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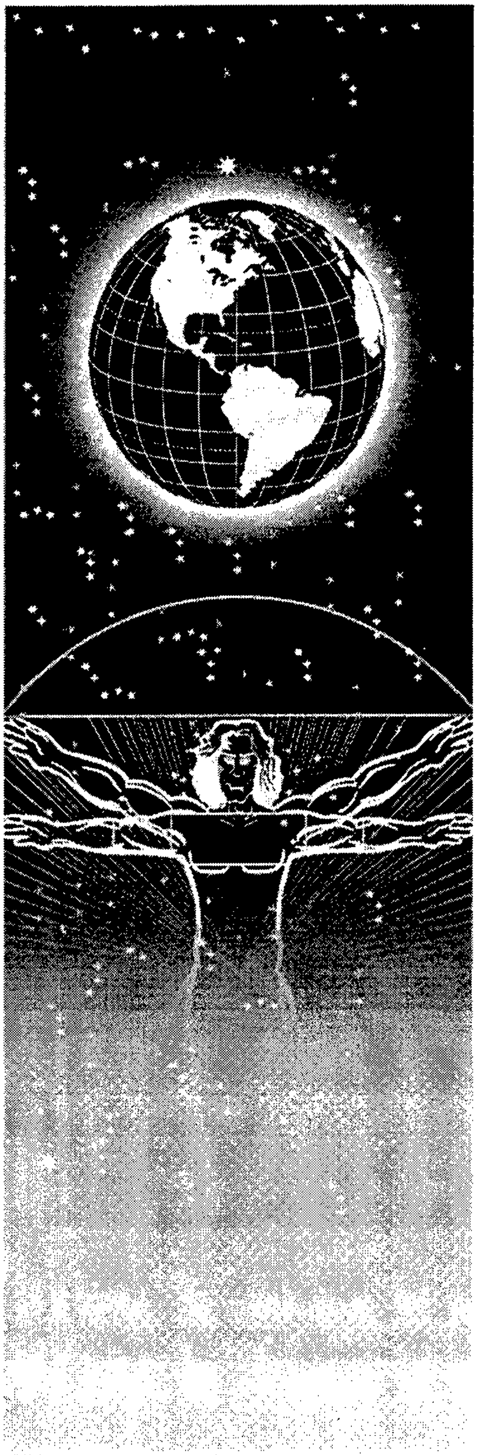

UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

SITUATION AWARENESS INFORMATION DOMINANCE & INFORMATION WARFARE

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FOR THE COMMANDER

JOHN F. KENT, COL, USAF, BSC
Acting Chief
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Information warfare and its primary objective of achieving information dominance over enemy forces have arisen as a major area of emphasis for future military actions. The concept of information dominance and the issues involved in attaining it are explored through a model of situation awareness within the context of the type of complex, distributed crews (or military units) envisioned in future military operations. Achieving information dominance involves far more than having more data than the enemy. It will require that available data be transformed into relevant information in a timely manner for a multitude of forces, each with varied and dynamically changing but inter-related information needs. Further, the information must be properly understood by each within the context of a joint mission. The difficulty of accomplishing this task is not to be underestimated, however. This is exactly where an understanding of situation awareness and the factors that impact it are essential. By examining what is known about how people access, assimilate and interpret information to develop situation awareness as well as how this fits within the decision making and action cycle, clear directions for the development of systems to support the goal of information dominance can be established.

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PREFACE

Present planning for future military actions emphasizes information warfare strategy and its primary objective: the achievement of information dominance over enemy forces. This report focuses on a subset of information warfare, intelligence-based warfare. It examines the concept of information dominance, and the issues involved in attaining it, through the application of a model of situation awareness. The model is applied within the context of a distributed military structure, in which tactical force elements are required to perform real-time decision making tasks in a complex dynamic environment. This effort was accomplished under Collaborative Systems Technology Branch Work Unit Number 71841046, "Crew Systems for Information Warfare." It was completed for Armstrong Laboratory, Collaborative Systems Technology Branch (AL/CFHI), under contract F41624-94-0-6000 for prime contractor, Logicon Technical Services, Inc. Mr. Donald Monk was the Contract Monitor.

A number of people contributed to the successful conclusion of this effort. The researchers especially acknowledge Mr. Gilbert Kuperman, of AL/CFHI, for his support and direction throughout the project. His assistance is deeply appreciated. The authors also recognize the following members of the LTSI staff for their invaluable assistance in the completion of this report: Mr. Robert L. Stewart for project management, Dr. Randall Whitaker for technical guidance, and Dr. Judi See and Ms. Elisabeth Fitzhugh for technical editing services.

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INFORMATION WARFARE

"The most important weapon now is information." (Oliver Morton, 1995)

As the United States has firmly moved into the information age, so has its means of engaging in warfare. Each of the major branches of the armed services has embraced the preeminence of controlling and manipulating information in fighting future battles (Dept. of the Air Force, 1995; U. S. Air Force, 1995; U. S. Army, 1995; U. S. Navy, 1995). Although information has always played a major role in military operations, this new emphasis greatly expands its role to that of a major realm for exerting control over the enemy (just as land, air, sea, and space are considered major realms [U. S. Navy, 1995]). This new emphasis, termed information warfare, is formally defined as "any action to deny, exploit, corrupt, or destroy the enemy's information and its functions; protecting ourselves against those actions; and exploiting our own military information functions" (U. S. Air Force, 1995).

> ***Information Warfare***
>
> *Any action to deny, exploit, corrupt or destroy the enemy's information and its functions; protecting ourselves against those actions; and exploiting our own military information functions.*
>
> (U. S. Air Force, 1995).

As the potential of information warfare (IW) strategies is unfolding, seven major types of IW have been identified (Libicki, 1995):

1. Command and control warfare – which seeks to decapitate or interfere with the enemy's command structure

2. Intelligence-based warfare – which exploits intelligent sensors, intelligent weapons, and real-time battle information for real-time decision making while denying the same to the enemy
3. Electronic warfare – which is involved in interfering with the enemy's transmission of information and protecting one's own information from the same
4. Psychological warfare – which involves information engineered to directly influence the public, troops, or leaders of opposing forces
5. Hacker warfare – which involves attacks on computer information and control systems
6. Economic information warfare – which attacks by blockading economic information flow, thus controlling markets
7. Cyberwarfare – which involves a wide class of activities from electronic terrorism (disruption of systems to wreck havoc) to simulated warfare scenarios

Although each of these categories of IW possesses intriguing possibilities for changing the ways in which future wars are conducted, the focus of the current discussion will remain centered on the second type: intelligence-based warfare. The objective in this class of IW is to achieve information dominance within the context of a traditional combat scenario or in future military operations, which may increasingly involve scenarios and activities other than war (such as terrorism, interdiction, or humanitarian relief efforts). Maintaining information dominance, "the ability to collect, control, exploit, and defend information while denying an adversary the ability to do the same" (Dept. of the Air Force, 1995), has become a major operational thrust. According to General Ronald R. Fogleman, "Dominating the information spectrum is as critical to conflict now as occupying the land or controlling the air has been in the past." (Dept. of the Air Force, 1995).

Information Dominance

The ability to collect, control, exploit, and defend information while denying an adversary the ability to do the same.

(Dept. of the Air Force, 1995)

An important component of the Air Force's ability to maintain air superiority during Korea and Vietnam was the use of sensor and electronic technologies that assisted aircrews in developing a comprehensive picture of the numbers and locations of enemy forces. This concept was greatly expanded during the more recent Persian Gulf War to the extent that it has been labeled "the first information war" (Campen, 1992; Mann, 1994). While many factors contributed to the great success of the U.S. led coalition forces against Iraq, their ability to speed up the cycle of collecting, disseminating, and using information to produce a new air tasking order every 72 hours (as compared to typical cycles of weeks) is considered a key component in that outcome. Coupled with this thrust was a highly successful program to severely disrupt the Iraqis' flow of information by destroying the command and control systems that provided critical tracking information for their fighters and surface-to-air missiles and by attacking Iraqi powergrids and telecommunications centers, which effectively disrupted internal communications systems (Mann, 1994). This situation left the Iraqis severely hampered in their ability to marshal and direct their forces, detect and respond to coalition tactics, and function as a cohesive fighting force.

The effect of this information dominance was a swift victory with an unprecedented minimization of casualties on the part of the coalition (Morton, 1995). While the information dominance was not complete (the coalition continued to have difficulty locating and destroying Iraq's mobile Scud missiles and strategic weapons facilities, for instance), the Gulf War effectively demonstrated the clear advantage of possessing information dominance in overcoming what was considered at the time to be a

very large, highly trained, and zealous fighting force that had the advantage of operating in its own backyard.

While information dominance has come to the forefront of current military thinking, the foundations for understanding this concept and the factors necessary to achieve it have been established in previous work on situation awareness. Throughout the late 1980's and early 1990's research was conducted on situation awareness, largely within the context of fighter aircraft, but also in relation to other aircraft platforms and non-aircraft operations. Loosely defined as knowing what is going on, achieving and maintaining a high level of situation awareness while denying it to the enemy has long been recognized as paramount (Press, 1986) and is the key to information dominance (see Table 1).

Table 1: Achieving Information Dominance

- Develop high levels of situation awareness among friendly forces
    - – knowledge of friendly disposition, actions, and intentions
    - – knowledge of enemy disposition, actions, and intentions
    - – knowledge of battlespace (terrain, conditions, etc.)
- Deny high levels of situation awareness to enemy forces
    - – lack of information
    - – misinformation

The objective of this treatise is to explore the concept of information dominance and the issues involved in achieving it by developing a model of situation awareness within the context of complex, distributed crews (or military units) as envisioned in future military operations. By examining what is known about how people access, assimilate, and interpret information to develop situation awareness and how this fits within the decision making and action cycle, clear directions for the development of systems to support the goal of information dominance can be established. As it will be

shown, achieving information dominance involves far more than having more data than the enemy. It will require that the data be transformed into the required information in a timely manner for a multitude of forces, each with varied and dynamically changing but inter-related information needs, and properly understood by each within the context of a joint mission. The difficulty of achieving this task is not to be underestimated; however, this is exactly where an understanding of situation awareness and the factors that impact it are essential. In order to delineate the factors that will be relevant for situation awareness and information dominance, it is necessary to develop a picture of the environment and conditions under which future battles will be fought.

Battlespaces of the Future: Conditions and Challenges

The U. S. Army, Air Force, Navy, and Marines have developed visions of the conditions under which future military operations will likely take place (U.S. Army, 1995; U. S. Navy, 1995; U. S. Air Force Scientific Advisory Board, 1995). These documents provide a foundation for understanding the facilitating mechanisms and challenges for information dominance. While there are some variations in the visions established by the major branches of the military (at least partially due to different missions and circumstances), many common features are apparent and are likely to have a significant impact on the situation awareness of future forces and their commanders.

Diverse Operations at Greater Distances

It is expected that U. S. forces will need to operate at considerable distances from home and existing bases as dictated by the actions of unpredictable hostile forces in various areas of the world. This necessitates "global awareness" — information of suitable resolution and short update rates from any location on the globe. Operations are also likely to involve a wide variety of missions ranging from fully declared wars through limited hostilities, to operations other than war, such as humanitarian relief missions. Each mission will consist of widely different rules of engagement and tolerance for casualties. This creates the need for a very flexible, disciplined fighting force which has at its disposal equally flexible technologies. Coupled with this trend towards more

diverse missions will be the trend towards more diverse personnel. Typical actions will involve multi-service branches and multi-national troops, each bringing with them different cultures, languages, and technologies.

Distributed Units

It is expected that future battles will involve more highly dispersed crews, thus creating targets that are more difficult for the enemy to hit. In addition, the technologies employed will involve a widespread network of smaller weapons and sensor systems (tied together through a common communications network) to supplement the current strategy of a few, concentrated, expensive systems. The key to distributing personnel and technological assets in such a way as to allow them to operate effectively will be networking — providing key communications links among crews, technologies, and command centers. It is believed that such a network will provide broader coverage and present a more difficult to defeat, diffused target than large, expensive concentrated assets. The network will be more difficult to take out, one system at a time, and will provide a huge amount of information shared over the entire force across a global battlespace.

Increased Tempo

The tempo of operations can be defined by the time period required to assess a situation and plan and carry out a military action. A key to success in the Gulf War was speeding up the pace at which that cycle occurred. The increased pace allowed friendly forces to stay ahead of the enemy, which in turn kept the enemy forces on the defensive and prevented them from dictating the conditions of battle. "We can use IW to slow and influence the enemy's decision making cycle, to prepare the battlespace before the start of open hostilities, and to dictate the battle on our terms" (U. S. Navy, 1995). Increased tempo has the added advantage of serving as a force multiplier by allowing existing forces to accomplish more in the same period of time (U. S. Air Force Scientific Advisory Board, 1995).

Distributed Decision Making

Associated with the use of many more distributed crews and technical systems will be the greater distribution of decision making at lower levels in the military hierarchy and, for certain functions, autonomously within the weapons/sensor system. The greater dispersion of many smaller crews and the increased tempo will require more local decision making within crews in order for them to react dynamically and take advantage of situational changes. Dealing with the huge volume of data created by the distributed network of sensors will also be greatly facilitated by providing a direct "sensor-to-shooter" link. A concept such as "Brilliant Pebbles;" in which weapons (e.g., missiles or mines) are equipped with sensors, microchips, and detonation power; provides autonomous or semi-autonomous units with the ability to act on their own to predefined classes of threats or situations and presents no single-point attack weakness.

When implemented, these operational conditions present incredible opportunities for information dominance. The combination of many small distributed systems and personnel, able to function in a more semi-autonomous manner within prescribed bounds, provides a more flexible and dynamic fighting force that will be able to carry out missions rapidly based on a far more accurate picture of the situation than has been previously possible. This allows the planning and actions of friendly forces to outpace those of the enemy. This scenario also presents many challenges, however.

Data Overload

While the development of a widely distributed information and command infrastructure will provide an unprecedented amount of data at heretofore unseen speeds, the sheer volume of data created presents a significant challenge. Data overload has already become a significant problem in advanced cockpits. During Desert Storm, the command center was equipped to handle over 700,000 phone calls and 152,000 messages per day (Mann, 1994). The development of the envisioned network of rapidly updating information sources will far surpass current data levels, which already exceed the capacity of people to sort through and assimilate effectively and rapidly. Developing systems capable of managing the volumes of data created by the network and processing it to

present needed information to a wide variety of forces with different goals and requirements in a manageable form is one of the biggest challenges to achieving the goal of information dominance.

Fog of War

Despite the incredible explosion of data, a high level of uncertainty and unpredictability always accompanies wartime actions. Rarely does everything go as planned, and rarely does the enemy act as expected. One can furthermore expect that the enemy will deliberately act to confound friendly information systems. Thus, one can expect a certain amount of information acquired may be false or may be conflicting. Dealing with the uncertainty of battle, missing information (possibly induced by inevitable breakdowns in the communications and data networks) and dissonant information will remain a challenge for situation awareness, even with the superior technologies envisioned.

Inter-crew Miscommunication and Coordination

Past warfare was characterized by the well planned and coordinated activities of many operational forces, each of which was required to follow a strict time-table and set of actions in order to carry out their part in the overall plan and remain deconflicted with other friendly forces. The pre-set plan was the major coordinating mechanism. However, rarely do all actions go as planned due to many factors, among them adverse weather conditions, mislocation of forces or supplies, and unpredictable actions on the part of the enemy. The ability to gain dynamic updates on the state of the battle and use this information to adjust plans and actions as needed is a major key to success. To accomplish this desire for increased tempo, the broad availability of networked information and more distributed decision making powers will create a situation in which more non-hierarchical transfer of information occurs between operational forces. As a result of the fact that different crews within a mission may have different goals, experiences, and perspectives (or even languages and cultures), each group may develop very different understandings of the situation from the same shared data. Bridging these

gaps (which may not always be readily apparent) will be a significant challenge in translating more data into better information so as to achieve the desired outcome.

Summary

The major features envisioned for the battlespace of the future are summarized in Figure 1. Future battles will incorporate diverse forces operating over large distances in a wide variety of missions. Operations will be characterized by the use of more widely distributed forces working with a network of distributed sensor and smart weapon systems, all connected through an integrated communications network. An increased tempo of operations will be achieved through the use of autonomous and semi-

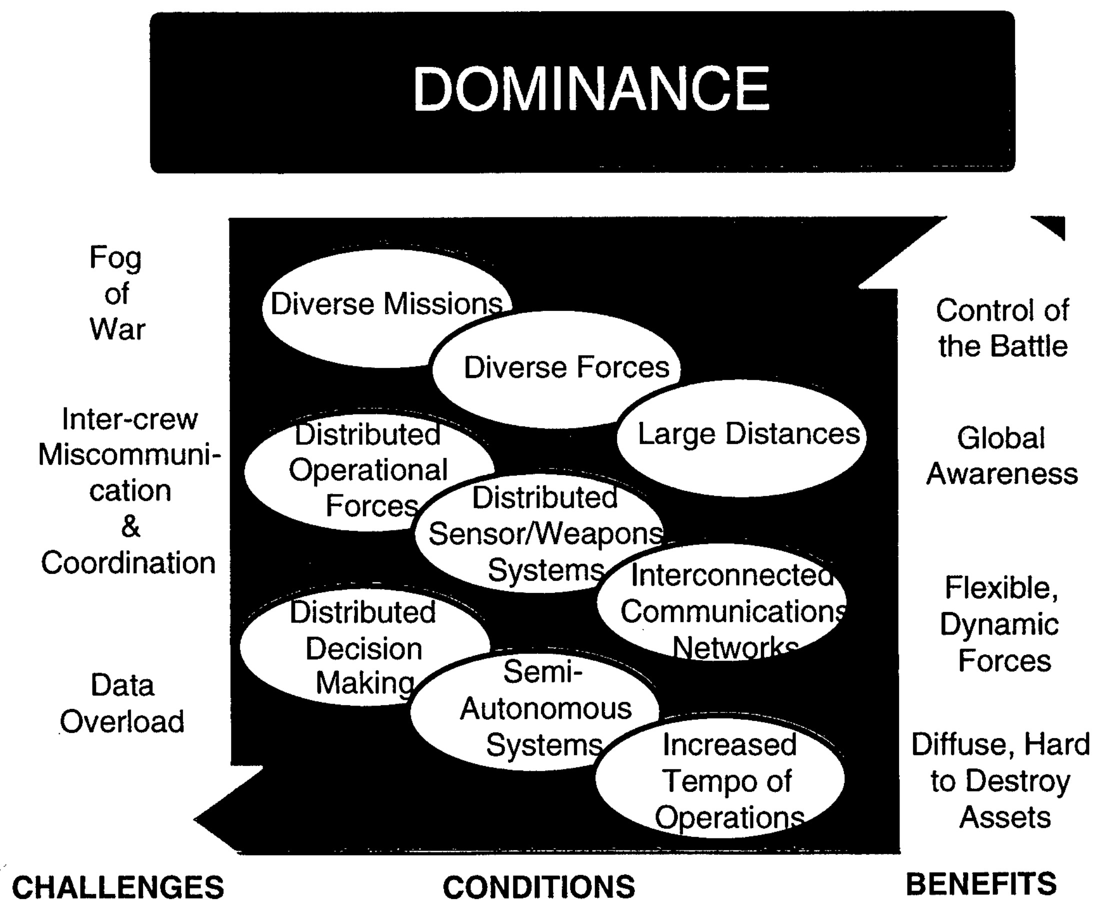

Figure 1. Conditions and Challenges for Information Dominance

autonomous systems and a greater reliance on distributed decision making at lower levels in the organization to take advantage of the increased flow of information. These factors can conceivably provide many advantages, including more flexible, dynamic forces who benefit from global awareness of the battlespace and decrease susceptibility to attack through their diffuse nature. This should allow friendly forces to essentially control the battlespace, dictating the terms and conditions of war. Several challenges must be overcome, however, before this vision will be realized. Using the increased flow of data will necessitate a much greater degree of inter-crew communication and coordination. There is also a significant potential for data overload that can coexist with the uncertainty and lack of needed information that accompanies the fog of war. Unless addressed, these factors can seriously undermine the ability to achieve information and battle dominance.

This treatise will explore ways to overcome these challenges to achieving the goal of information dominance. By examining a model of situation awareness and decision making in complex, distributed crews, critical system design and training issues will be established. Factors for achieving and depriving the enemy of situation awareness will be provided as a means of achieving information dominance. Previous work on situation awareness, which has concentrated on the individual, will then be expanded to focus on situation awareness at the level of the operational team and as it exists across multiple, distributed teams. By examining the factors necessary for achieving situation awareness at this level, the goal of achieving information dominance across the battlespace can be realized.

Developing systems capable of managing the volumes of data created by the network and processing it to present needed information to a wide variety of forces with different goals and requirements in a manageable form is one of the biggest challenges to achieving the goal of information dominance.

DECISION MAKING IN THE COMBAT ENVIRONMENT

Effective decision making is at the heart of effective action. A general model describing how decision making takes place will be examined as it relates to the combat officer. This discussion, which is not meant to be exhaustive, will set the stage for understanding the critical role that situation awareness plays in achieving information dominance.

OODA Loop

The true goal of war, even in defensive actions, is to exert one's will over the enemy. Doing so involves developing and executing a plan of action and responding to the enemy more quickly than it can respond to you. This process has been described by the Observe-Orient-Decide-Act (OODA) loop (Boyd, 1997), as shown in Figure 2.

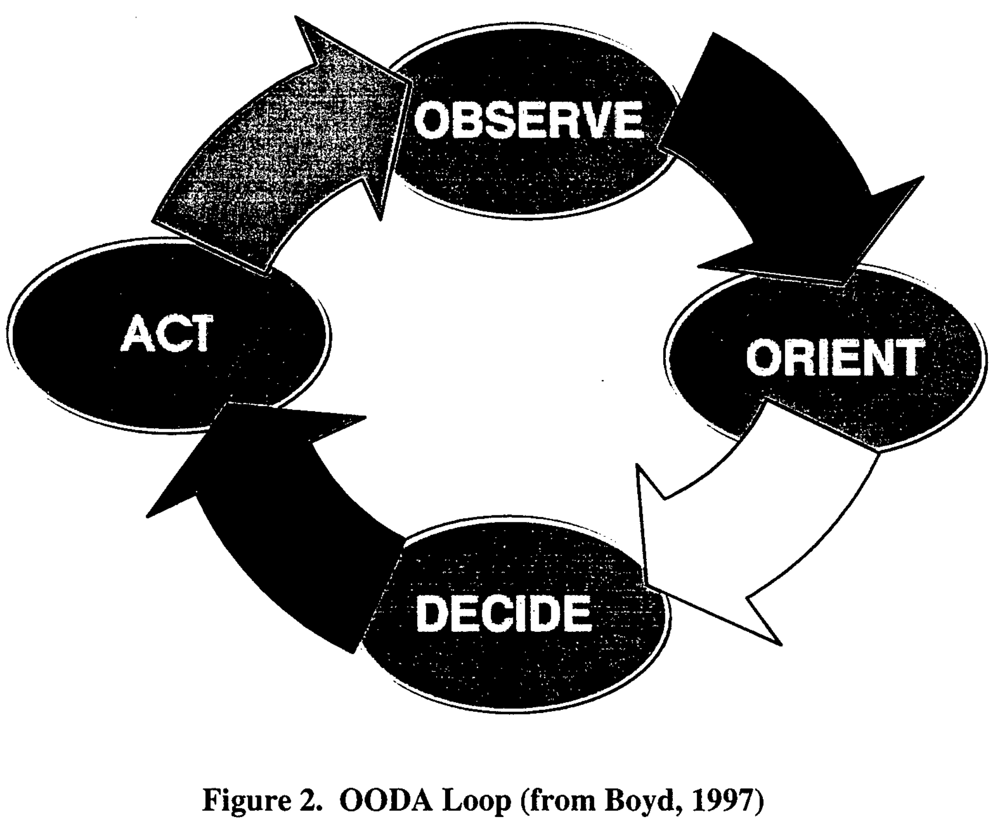

Figure 2. OODA Loop (from Boyd, 1997)

Col. John Boyd equates the OODA loop to the command and control loop. Four major stages are characterized by the model:

1. Observation of information is achieved through available personnel, technologies, and intelligence functions.
2. Orientation is provided based on experiential and cultural factors of the decision maker, determining which information is to be observed and how it should be used.
3. Decisions as to appropriate courses of action are made by command elements.
4. Actions are carried out by field units, which in turn feed more information on the changing situation into the observation cycle.

This loop can be conceived of as occurring at many levels within the organization: (a) crews in the battle acting on information directly received, (b) local command organizations acting on information derived from many sources to plan and coordinate the activities of many crews, and 3) theater and national level staffs, which operate on more global information and plan actions to be executed across a larger range of forces. As shown in Figure 3, the objective of information dominance is to reduce the time required to complete the OODA loops (at all levels) on the friendly side, while increasing it for the enemy. This is what permits friendly forces to use information dominance to their advantage, allowing them to control the battle and gain victory.

The objective of information dominance is to reduce the time required to complete the OODA loop on the friendly side, while increasing it for the enemy.

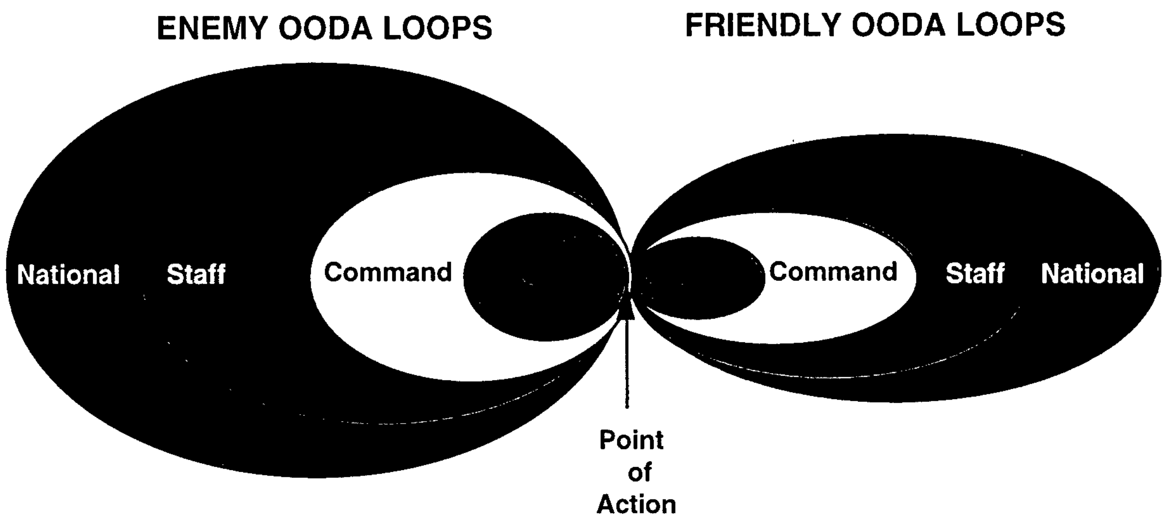

Figure 3. Information Dominance: Reduce Friendly OODA Loops & Increase Enemy OODA Loops

To determine how to accomplish this goal, a great deal can be gained from examining how people process information and make decisions in dynamic, complex systems (as the OODA loop is essentially carried out by people — acting as individual information processors in a collective manner). There has been a considerable amount of research on this subject, both in military and non-military problem domains.

Normative Decision Models

Early models of human decision making presumed a "rational" decision maker who examined a set of alternative actions and weighted the attributes of each alternative according to some internally held value system in order to attain a mathematically consistent "best choice." Research for the past two decades, however, has shown that people do not conform to such a model. They are much more likely to use simplifying heuristics and display systematic biases in their decision process when compared to such a model (Tversky & Kahneman, 1981). Nonetheless, this normative model of decision making, classical decision theory, has remained as a prescriptive model frequently taught

as the correct way to make decisions. Criticisms of this model abound, however (Beach & Lipshitz, 1993):

1. Such a model is based on static laboratory tasks that do not contain the essential situational elements found in real world tasks.
2. The model is based on a gambling phenomenon, which assumes multiple decisions or trials, also frequently not found in the real world.
3. Even when trained, experts will rarely use classical decision theory as it does not capture essential elements of the task.
4. Such a model is backward looking (based on historical probabilities) rather than forward looking, which is needed in many new situations.

Such models are applicable only for well defined problems of high importance in which there is plenty of time for evaluating options (Endsley, 1997). With the exception of long-range planning, under most decision circumstances to be encountered in real-time military operations, people will not operate according to a normative decision model. In such circumstances, it is important to understand how they do make decisions, so that systems can be designed to support them properly.

Descriptive Decision Models

The military environment includes problems that are generally ill-structured. Further, information about the environment is continually changing and is often incomplete and ambiguous. The goals of decision makers in these environments are often fluid with many competing goals that shift over time. The stakes are usually high and decision makers frequently have very severe time constraints. Furthermore, in this environment decision makers do not make single discrete decisions, but rather must make a series of decisions in an effort to bring the environment into line with their goal state. These domain characteristics match those included in a model of decision making that has been labeled naturalistic decision making (Orasanu & Connolly, 1993).

A naturalistic model of decision making specifies a process in which the decision maker's perceived situation is categorized based on recognized classes of situations for

which known courses of action apply. Research indicates that in environments such as those described, people rarely consider multiple alternatives. Instead, they make decisions using a process of situation recognition and pattern matching to memory structures in order to make rapid decisions (Dreyfus, 1981; Endsley, 1994a; Klein, 1986, 1989, 1993; Lipshitz, 1987; Nobel, Boehm-Davis, & Grosz, 1987; Sweller, 1988). This has been described as a process in which pattern matching mechanisms draw upon long term memory to classify a situation based on schema of prototypical situations (Endsley, 1995b). Stored responses or scripts are frequently tied to these situation classifications, yielding an almost immediate response selection from memory, as shown in Figure 4.

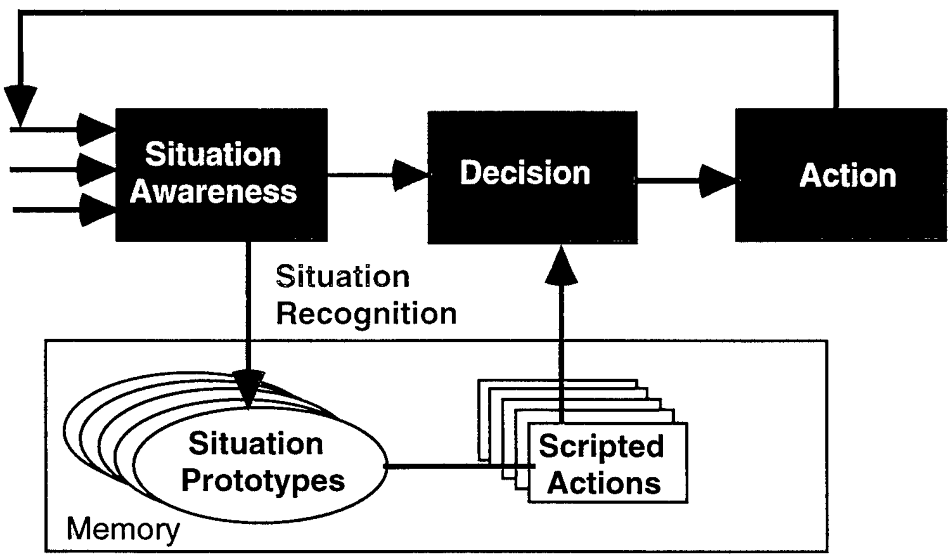

Figure 4. Descriptive Model of Decision Making

Research that has been done in military environments seems to support this type of model. Klein (1989) studied fire ground commanders operating under similar conditions and found that a conscious deliberation of solution alternatives was rarely observed. Rather, the majority of the time the experts focused on classifying the situation. Such classifications immediately yield the appropriate solution from memory. Kaempf, Wolf, and Miller (1993) reported that of 183 decisions by tactical commanders, 95% used this type of recognition decision strategy, involving either feature matching to situation

prototypes (87%) or story building (13%). While much research conducted emphasizes the decision processes of experts, novices must also focus a considerable amount of their effort on assessing the state of the environment in order to make decisions. Cohen (1993) points out that metacognitive strategies may become important in these cases, as forming an assessment of the situation becomes more challenging.

When making decisions in this way, the major emphasis is primarily on classifying the situation, with very little effort being devoted to an examination of multiple action alternatives (Klein, 1989). The decision maker's assessment of the situation, or situation awareness, therefore, becomes the major factor driving the quality of the decision process. Even when more analytical decision processes are used, determining the situation is equally critical and difficult as the environment is ill-defined and uncertain.

The contribution of information dominance is in providing a means of reducing the time required to properly assess a situation, make a decision, and carry out effective actions. In examining how people perform this process, achieving situation awareness is revealed as the key step upon which success most often hinges. Understanding what situation awareness consists of and finding ways to develop high levels of this commodity in the challenging environment of combat are therefore paramount.

The decision maker's situation awareness is the major factor driving the quality of the decision process.

SITUATION AWARENESS

Given the important role of situation awareness in decision making, understanding what situation awareness is and the factors that affect it will point the way towards essential techniques for taking advantage of the capabilities brought by the information age.

Definition and Description

Situation awareness (SA) is formally defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988). Situation awareness therefore involves perceiving critical factors in the environment (level 1 SA), understanding what those factors mean, particularly when integrated together in relation to the person's goals (level 2), and understanding what will happen with the system in the near future (level 3). These higher levels of SA allow decision makers to function in a timely and effective manner.

Situation Awareness
The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. (Endsley, 1988)

Level 1 SA – Perception of the Elements in the Environment

The first step in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment. A pilot needs to perceive important elements such as other aircraft, mountains, or warning lights, along with their relevant characteristics.

In combat, enemy aircraft and ground threats, friendly forces, and environmental features (and their important characteristics) must all be detected.

Level 2 SA – Comprehension of the Current Situation

Comprehension of the situation is based on a synthesis of disjointed level 1 elements. Level 2 SA goes beyond simply being aware of the elements which are present, to include an understanding of the significance of those elements in light of one's goals. The decision maker puts together level 1 data to form a holistic picture of the environment, including a comprehension of the significance of objects and events. For example, a military pilot or tactical commander needs to comprehend that the appearance of enemy aircraft arrayed in a certain pattern and in a particular location indicates certain things about their objectives. A novice decision maker may be capable of achieving the same level 1 SA as more experienced decision makers, but may fall far short of being able to integrate various data elements along with pertinent goals in order to comprehend the situation as well.

Level 3 SA – Projection of Future Status

The ability to project the future actions of the elements in the environment, at least in the very near term, forms the third and highest level of situation awareness. This is achieved through knowledge of the status and dynamics of the elements and a comprehension of the situation (both level 1 and level 2 SA). For example, knowing that a threat aircraft is currently offensive and is in a certain location allows fighter pilots or military commanders to project that the aircraft is likely to attack in a given manner. This gives them the knowledge (and time) necessary to decide on the most favorable course of action to meet their objectives.

Situation awareness involves far more than simply perceiving information in the environment. It includes comprehending the meaning of that information in an integrated form compared to one's goals, and providing projected future states of the environment. These higher levels of SA are particularly critical for effective decision making in a dynamic environment such as combat.

Situation Awareness in the Battlespace

In combat, different crews will have different missions and goals; therefore, the "elements" they will need to be aware of in their situations will be different. These elements can be specified for each crew member as a function of his/her goals which may include categories such as those listed in Table 2.

Table 2: Goals in the Battlespace

- Detection/identification
  - targets
  - friendly/hostile elements
  - environmental features
- Navigation/localization
  - self
  - others
- Engagement of enemy
  - maneuvering•
  - targeting
  - firing
- Communications
  - within team
  - headquarters
  - between teams
- Mission planning/replanning
- Tactics development

In relation to the OODA model of decision making, situation awareness can be seen as a more detailed description of the observe and orient stages of the model, as

shown in Figure 5, that more accurately describes how people process information in dynamic decision making.

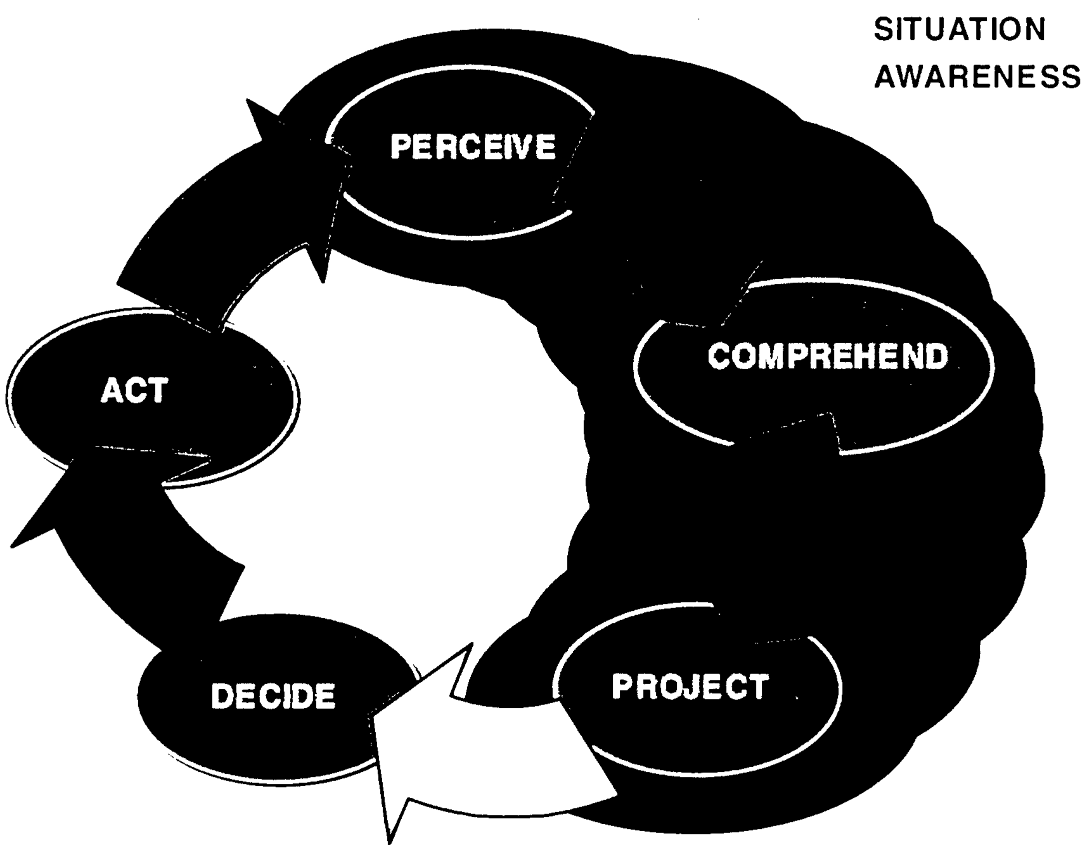

Figure 5. Situation Awareness in the OODA Loop

Cooper (1995) describes a cognitive hierarchy in relation to dominant battlespace knowledge, which includes four levels: data, information, knowledge, and understanding. This hierarchy is similar to previous work on situation awareness which has discussed the need for systems to develop *information* from the raw *data* provided by most avionics and electronic systems (Endsley & Bolstad, 1993). SA, which exists at the level of the individual, encompasses both *knowledge* and *understanding* as defined by the hierarchy, as shown in Figure 6. Cooper makes a point similar to that made here in stating that dominant battlespace knowledge must be achieved across this entire cognitive hierarchy. That is, to be effective, approaches for achieving dominant battlespace knowledge (i.e., information dominance) must develop a means of creating understanding (the highest

levels of SA) by more effectively turning data into information and information into knowledge. This can be seen to be a direct function of the processes and technologies available for creating SA from the data available in the environment.

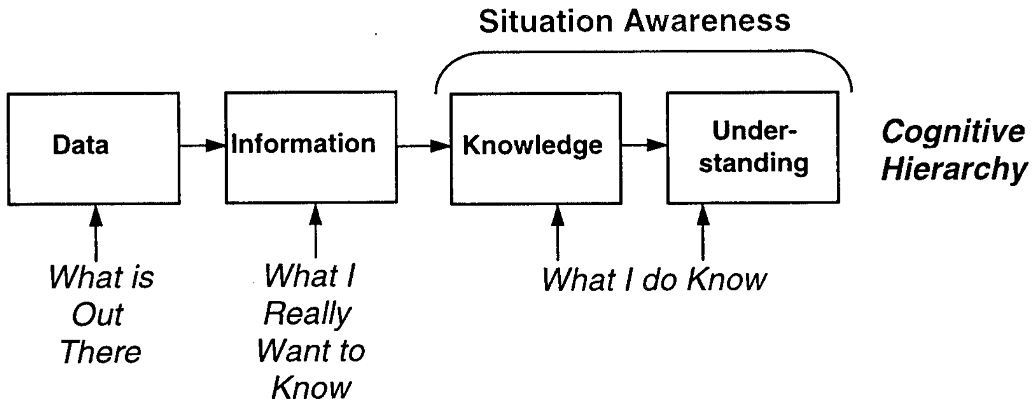

Figure 6. Relationship between Cognitive Hierarchy and Situation Awareness

Model of Situation Awareness

In order to provide an understanding of the processes and factors that influence the development of SA in complex settings such as combat, a theoretical model describing the factors underlying situation awareness has been developed (Endsley, 1988, 1995b). This model brings together a great deal of research on cognition into an organized framework for conceptualizing SA. Key features of the model will be summarized here and are shown below in Figure 7. This model includes a consideration of the features of individuals that determine their ability to acquire SA in complex settings and the features of the system that act upon these abilities. Important features and mechanisms that individuals use to achieve SA include attention and working memory, mental models and schema, use of goals and goal-directed processing, preconceptions or expectations, and automaticity, as shown in Figure 7.

Attention and Working Memory

Individuals possess a limited amount of attention that they can allocate to taking in and processing environmental information. They also have a limited amount of working memory — a system for processing and retaining information that is perceived. In dynamic environments, the development of situation awareness and the decision process are restricted by limited attention and working memory capacity for novices and those in novel situations. Direct attention is needed for perceiving and processing the environment to form SA, for selecting actions and executing responses. In complex and dynamic environments, information overload, task complexity, and multiple tasks can quickly exceed a person's limited attention capacity. For example, a single seat aircraft flying a low-level mission at night remains a highly challenging environment for overloading the pilot.

Because the supply of attention is limited, more attention to some information may mean a loss of SA on other elements. The resulting lack of SA can result in poor decisions leading to undesirable outcomes. In a review of National Transportation Safety Board accident reports involving commercial airliners, for instance, poor SA resulting from attention problems in acquiring data accounted for 31% of accidents involving pilot error (Endsley, 1995a).

Similarly, working memory capacity can act as a limit on SA. In the absence of other mechanisms, most of a person's active processing of information must occur in working memory. New information must be combined with existing knowledge and a composite picture of the situation developed (level 2 SA). Projections of future status (level 3 SA) and subsequent decisions as to appropriate courses of action must occur in working memory as well.

For novices, or those dealing with novel situations, limited working memory and attention constitute the main bottleneck for situation awareness and can seriously constrain the decision making process. With experience, however, people develop mechanisms that can overcome these limitations: 1) expectations, 2) mental models and schema, 3) goal directed processing, and 4) automaticity.

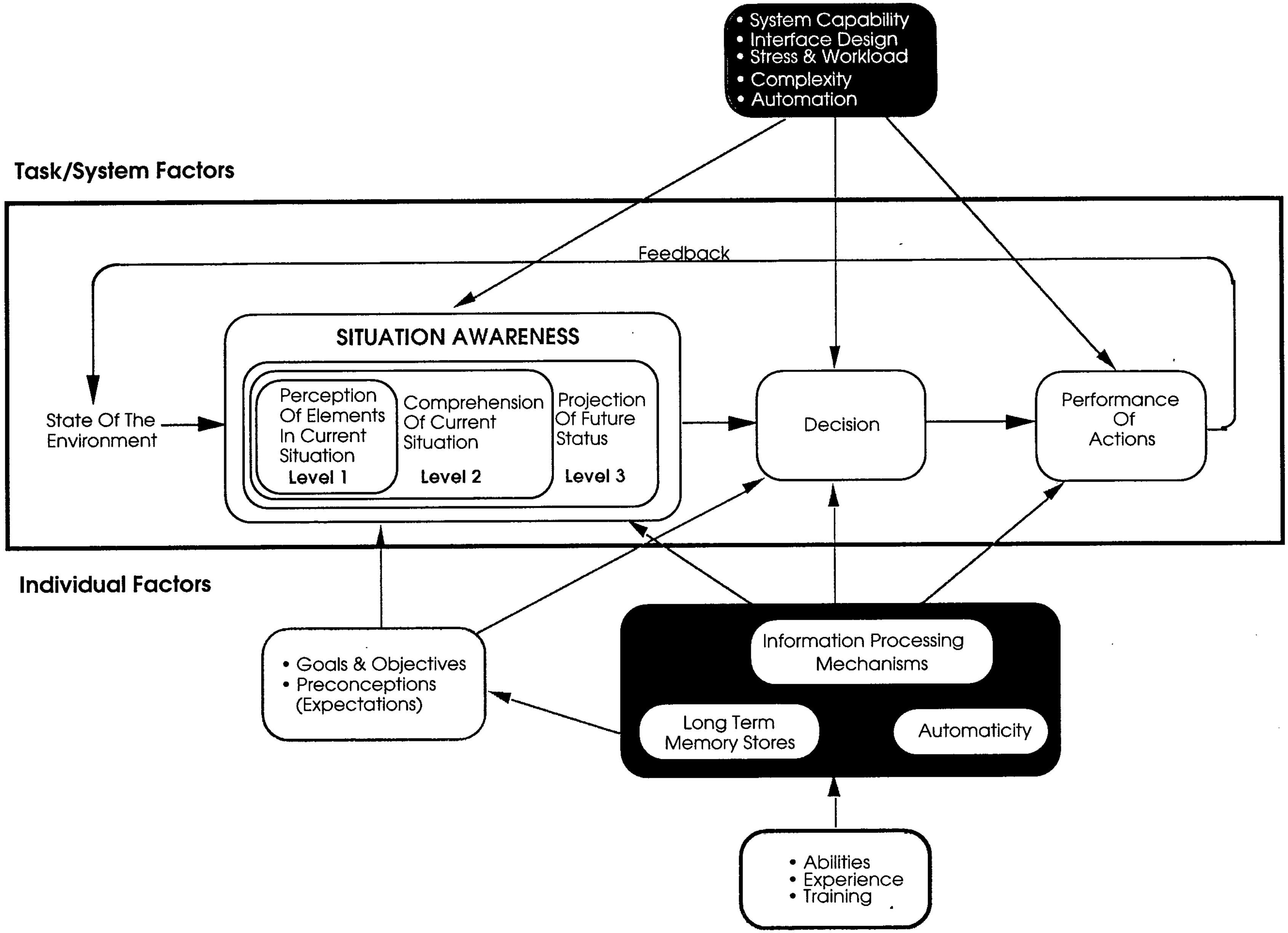

Figure 7. Model of Situation Awareness in Dynamic Decision Making (from Endsley 1995b)

Mental Models and Schema

In practice, experienced decision makers are able to use long-term memory stores, most likely in the form of schema (situation prototypes) and mental models, to circumvent these limits for learned classes of situations and environments. These mechanisms provide guidance on the critical features of the environment that should be attended to and for the integration and comprehension of that information and the projection of future events, either directly or through related situation prototypes. They also allow for decision making on the basis of incomplete information and under uncertainty.

For example, a pilot may perceive several aircraft (considered to be important elements per the mental model) which are recognized as enemy fighter jets (based on critical cues) approaching in a particular spatial arrangement (forming level 1 SA). By pattern-matching to prototypes in memory associated with the mental model, these separate pieces of information may be classified as a particular recognized aircraft formation (level 2 SA). According to an internally held mental model, the pilot is able to generate likely attack scenarios for this type of formation when in relation to an aircraft with the location and flight vector of his/her own ship (level 3 SA). Based on this high level SA, the pilot is then able to select prescribed tactics (a script) that dictate exactly what evasive maneuvers should be taken.

The development of mental models is extremely important for SA. They allow for rapid situation comprehension and direct crew members as to which features of the environment are important. When the state of their mental model (determined by the current situation) matches known states (situation prototypes), decision making is even further simplified. A major advantage is that the current situation does not need to be exactly like one encountered before due to the use of categorization mapping (a best fit between the characteristics of the situation and the characteristics of known categories or prototypes). Furthermore, this entire process can be almost instantaneous due to the superior abilities of human pattern matching mechanisms.

The use of mental models also provides default information for decision makers. These default values (expected characteristics of elements based on their classification) allow people to predict behavior under incomplete or uncertain information. Thus expert pilots will have access to reasonable default information about aircraft and enemy behavior, yielding more effective decisions than novices who will have far more difficulty operating with missing data. This is an important coping mechanism for forming SA in challenging domains such as combat, where information may be missing or overload prevents acquiring all the information needed.

An important aspect of SA is the crew member's degree of uncertainty about the quality of their internal model and their uncertainty about future projections based on the model. They are still able to make decisions effectively despite numerous uncertainties. As they retain this confidence information, however, it can have a large impact on how they choose to act on that SA. Small shifts in these uncertainties can dramatically change resultant conclusions.

Analysis of the issues related to combat losses during the air war in Vietnam indicate that most pilots were lost during their initial ten missions. During this period the aircrew were still new to combat and had not yet developed the mental models and schema that are critical for rapid situation assessment and decision making in this environment. As a result of this experience, the Air Force created training programs such as Red Flag and Green Flag. These programs are effective in that they allow aircrews the opportunity to develop the necessary mental models and schema that will allow them to be effective early on in actual combat without encountering the losses that come with combat experience.

Data-driven and Goal-driven Processing

In a data-driven process, environmental features are processed in parallel through preattentive sensory stores where various signal properties are detected, thus providing cues for further focalized attention. Cue salience has a large impact, therefore, on which portions of the environment are attended to, these elements forming the basis for the first level of SA. In addition, people can operate in a goal-driven fashion. With experience,

they gain a strong understanding of their goals and which goals should be active at which times. Situation awareness is highly impacted by a crew member's goals and expectations. These two components influence how attention is directed, how information is perceived, and how it is interpreted. In a top-down, goal-directed decision process, their goals and plans direct which aspects of the environment are attended to. That information is then integrated and interpreted in light of these goals to form level 2 SA. Activities are then selected by the crew member which will bring the perceived environment into line with their plans and goals based on that understanding.

On an ongoing basis, trade-offs between top-down and bottom-up processing will occur in a dynamic environment such as the operational military domain. While goal-driven processing is occurring, the crew member can be very efficient, seeking out specific information and using it to achieve the goal. When data-directed processing is occurring, patterns in the environment may be recognized indicating that new plans are necessary to meet active goals or that different goals should be activated. In this way a crew member's current goals and plans may change in response to events in the environment. Alternating top-down and bottom-up processing is essential for processing information effectively in a dynamic environment. Major problems occur when either of these processes cease to operate. Those who are strictly data-driven can become overloaded and will not achieve their goals effectively. Those who are strictly goal-driven will lose sight of important information that indicates new, more important goals.

Expectations

A pattern dictated by long-term memory indicates relative priorities of information and the frequency with which information changes. This knowledge is used to direct information sampling, a strategy frequently used to circumvent attention limits. Working memory also plays an important role in this process, allowing the crew member to modify attention deployment on the basis of current goals or other information perceived, thus forming expectations. Preconceptions or expectations about information can effect the speed and accuracy of the perception of information. Repeated experience in an environment allows crew members to develop expectations about future events that

predispose them to perceive the information accordingly. Pre-mission briefs and simulations of a particular mission act to create strong expectations that will direct attention and interpretations during the real thing. Crew members will process information faster if it is in agreement with those expectations and will be more likely to make an error if it is not (Jones, 1977).

Automaticity

SA can also be impacted by automaticity of cognitive processes. This may be useful in overcoming attention limits, but may leave the crew member susceptible to missing novel stimuli. Developed through experience and a high level of learning, automatic processing tends to be fast, autonomous, and effortless (Logan, 1988). Automatic processing is advantageous in that it provides good performance with minimal attention allocation. While automaticity may provide an important mechanism for overcoming processing limitations for achieving SA and making decisions in complex, dynamic environments, it also creates an increased risk of being less responsive to new stimuli as automatic processes operate with limited use of feedback. When using automatic processing, a lower level of SA can result in non-typical situations, decreasing decision timeliness and effectiveness. While automaticity of psychomotor tasks (e.g., stick and rudder flight control) is advantageous, it needs to be guarded against for cognitive tasks in critical situations such as flight or battle.

Summary of Individual Factors Impacting SA

To summarize the key features of the individual affecting SA in this model, a crew member's situation awareness is restricted by limited attention and working memory capacity. The crew member can largely circumvent these limits by providing for the integration and comprehension of information and the projection of future events (the higher levels of SA), even on the basis of incomplete information and under uncertainty. The use of these models depends on pattern matching between critical cues in the environment and elements in the model. Schema of prototypical situations may also be associated with scripts to produce single-step retrieval of actions from memory. Situation awareness is largely impacted by a crew member's goals and expectations, which

influence how attention is directed, how information is perceived, and how it is interpreted. This top-down processing will operate in tandem with bottom-up processing in which salient cues will activate appropriate goals and models. In addition, automaticity may be useful in overcoming attention limits; however, it may leave the crew member susceptible to missing novel stimuli, which can negatively impact SA.

The model in Figure 7 also depicts many task and environmental features relevant to combat which can be understood in light of these cognitive mechanisms: 1) system capability, 2) interface design, 3) stress and workload, 4) complexity, and 5) automation.

System Design

SA does not exist by creating information in some technical system. SA only exists when it is developed within the cognition of a person who assesses that information. Figure 8 shows the sequence by which a crew member gains access to information from the environment (Endsley, 1989b). Some information may be acquired directly. In addition, however, there will usually be intervening technical systems which acquire information and present it to the crew member.

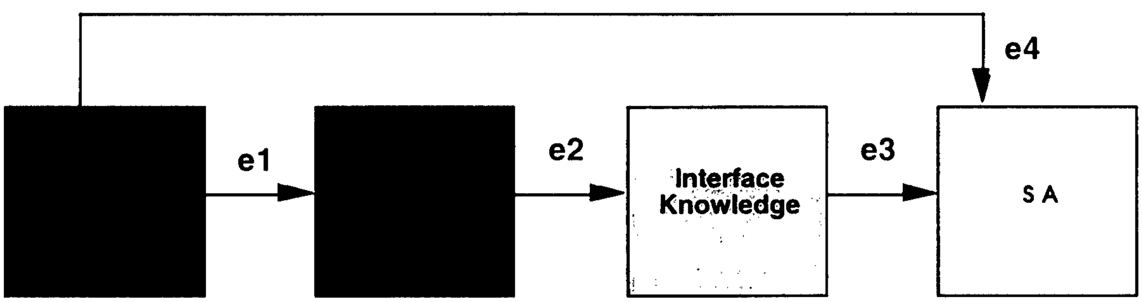

Figure 8. Situation Awareness Inputs (from Endsley, 1995b)

The system will acquire a certain amount of data on the phenomenon available in the world (with a certain degree of veracity), and a certain amount of that information will be available through the interface. Of that, a certain amount will be accurately absorbed by the human crew member. In this process, transmission error, defined as a loss of information, can occur at each transition. The first external issue impacting on SA, therefore, is the degree to which the system acquires the needed information from the environment. The

second major issue involves the display interface for providing that information to the crew member.

Interface Design

The way in which information is presented via the crew interface will largely influence SA by impacting how much information can be acquired, how accurately it can be acquired, and to what degree it is compatible with the crew member's SA needs. Hence, SA has become a topic of great concern in human interface design efforts. In general, one seeks designs that will transmit needed information to the crew member without undue cognitive effort. In this light, mental workload has been a consideration in design efforts for some time. At the same time, the level of SA provided (the outcome of that process) needs to be considered. Guidelines for creating SA-oriented system designs have been developed (Endsley, 1995b) and applied to system design efforts (Endsley, 1994b). These are summarized to include:

1. The degree to which displays provide information that is processed and integrated in terms of level 2 and 3 SA requirements will positively impact SA. For instance, directly portraying the amount of time and distance available on the fuel remaining in an aircraft would be preferable to requiring the pilot to calculate this information based on lower level data — fuel, speed, altitude, etc.
2. The degree to which information is presented in terms of the crew member's major goals will positively impact SA (i.e., organized so that the information needed for a particular goal is co-located and directly answers the major decisions associated with the goal). For example, for the goal of weapons employment, factors such as opening/closing velocity, weapon selected and firing envelope, probability of kill, target selected, and time to employment would be relevant elements that should be presented in an integrated form for this goal.
3. In that mental models and schemata are hypothesized to be key features used for achieving the higher levels of SA in complex systems, the critical cues used for activating these mechanisms need to be determined and made salient in the interface

design. In particular, those cues that will indicate the presence of prototypical situations will be of prime importance.

4. Designs need to take into consideration both top-down and bottom-up processing. In this light, environmental cues with highly salient features will tend to capture attention away from current goal-directed processing. Salient design features (e.g., color, flashing lights) should be reserved for critical cues that indicate the need for activating other goals, and should be avoided for non-critical events.
5. Provide global SA — an overview of the situation across goals — at all times, while providing the crew member with detailed information related to the goals of current interest, as required. Global SA is hypothesized to be important for determining current goals and for enabling projection of future events. Avoid system designs which restrict or automatically filter the provision of information based on current goals.
6. While filtering out information on relevant SA elements is hypothesized to be detrimental, the problem of information overload must still be considered. The filtering of extraneous information (not related to SA needs) and reduction of data (by processing and integrating low level data to arrive at SA requirements) should be beneficial to SA.
7. One of the most difficult and taxing parts of SA is the projection of future states of the system. This is hypothesized to require a fairly well developed mental model. System generated support for projecting future events and states of the system should directly benefit level 3 SA, particularly for less experienced operators.
8. The ability to share attention between multiple tasks and sources of information will be very important. System designs that support parallel processing of information should directly benefit SA. For example, the addition of voice synthesis or three dimensional localized audio cues to the visually overloaded cockpit is predicted to be beneficial on this basis.

Workload

The link between SA and workload is depicted in Figure 9 (Endsley, 1993b). Under low to moderate workload, the level of SA crew members have can be independent of

workload level. They may have low SA and not be working very hard to achieve higher SA, or they may have high SA without having to work very hard (through the benefits of a well designed system). They may be working fairly hard and be rewarded with a high level of SA, or they may still have low SA as their efforts might be ineffective or they may misinterpret the information they have acquired.

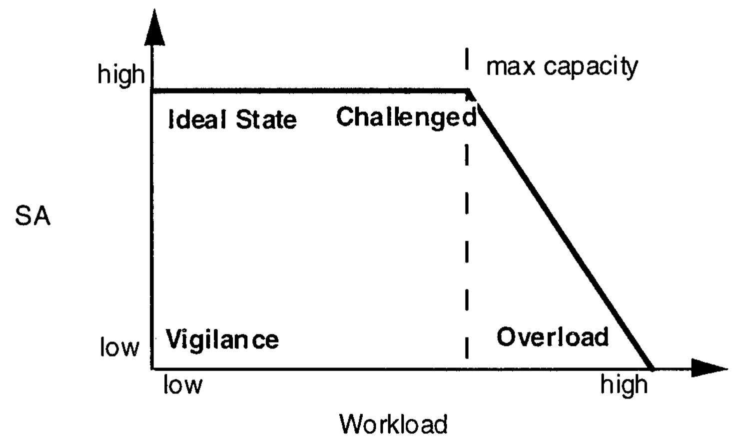

Figure 9. Relationship Between SA and Workload (from Endsley, 1993b)

At very high levels of workload, however, SA will decline. If the volume of information and number of tasks are too great, SA will suffer as only a subset of information can be attended to, or the crew member may be actively working to achieve SA, yet suffer from erroneous or incomplete perception and integration of information. Thus, data or system designs that overload the crew member can have a major impact on SA. It is important that technologies and data systems implemented for use in combat not increase workload, particularly when high workload tasks already exist.

Complexity

A major factor creating a challenge for SA is the complexity of the systems that must be operated. The more complex systems are to operate, the greater the increase in the mental workload required to achieve a given level of SA. When that demand exceeds human capabilities, SA will suffer. However, system complexity may be somewhat moderated by the degree to which the crew member has a well developed internal representation of the

system to aid in directing attention, integrating data, and developing the higher levels of SA, as these mechanisms may be effective for coping with complexity. Developing those internal models will require a considerable amount of training; thus, extremely complex systems and data presentations need to be avoided wherever possible.

Automation

SA may also be negatively impacted by the use of automation. Pilots working with automation have been found to have a diminished ability to detect system errors and subsequently perform tasks manually in the face of automation failures (Billings, 1991; Moray, 1986; Wickens, 1992; Wiener, 1980). While some of this problem may be due to a loss of manual skills as a result of automation, loss of SA has also been shown to be a critical component of the problem (Endsley & Kiris, 1995).

Crew members who have lost SA may be both slower to detect problems and additionally will require extra time to re-orient themselves to relevant system parameters in order to diagnose a problem and take over manually. The degree to which automation and semi-automation is incorporated with the new technologies being developed for the future battlespace needs to be carefully examined for this potential impact.

Stressors

Several types of stress factors exist in the combat environment which may act to impact SA, including (a) physical stressors, such as noise, vibration, heat/cold, lighting, atmospheric conditions, boredom or fatigue, cyclical changes, and (b) social/psychological stressors, such as fear or anxiety, uncertainty, importance or consequences of events, self-esteem, career advancement, mental load, and time pressure (Hockey, 1986; Sharit & Salvendy, 1982). A certain amount of stress may actually improve performance by increasing attention to important aspects of the situation. A higher amount of stress can have extremely negative consequences, however, as accompanying increases in autonomic functioning and aspects of the stressors can act to demand a portion of a crew member's limited attentional capacity (Hockey, 1986).

Stressors can affect SA in a number of different ways, including attentional narrowing. Under perceived danger, a decrease in attention has been observed for

peripheral information — those aspects which attract less attentional focus (Bacon, 1974; Weltman, Smith, & Egstrom, 1971). There is also an increased tendency to sample dominant or probable sources of information under stress (Broadbent, 1971). This is a critical problem for SA, leading to the neglect of certain elements in favor of others. In many cases, such as in emergency conditions, it is those factors outside the crew member's perceived central task that prove to be lethal. Premature closure (arriving at a decision without exploring all information available) has also been found to be more likely under stress (Janis, 1982; Keinan, 1987; Keinan & Friedland, 1987). This includes considering less information and attending more to negative information (Janis, 1982; Wright, 1974). Furthermore, scanning of information under stress is scattered and poorly organized (Keinan, 1987; Keinan & Friedland, 1987; Wachtel, 1967).

A second way in which stress may impact SA is through decrements in working memory capacity and retrieval (Hockey, 1986; Mandler, 1979). The degree to which working memory decrements will impact SA, however, depends on the resources available to the individual crew member. In tasks where achieving SA involves a high working memory load, a significant impact on SA levels 2 and 3 would also be expected. If long-term memory stores are available to support SA, less effect will be expected. (Emergency training seeks to build up these long-term memories for just this reason.)

While anxiety is a common stressor in the battlespace, other common stressors, such as fatigue and environmental conditions (cold, heat, humidity), can also take a significant toll on performance and SA. To a certain degree, the impact of stressors on SA is a given part of the combat environment. Many new system technologies can exacerbate these effects, however, if they interfere with scanning of relevant information in the environment (e.g., by encouraging heads-down behavior), load working memory, or encourage dependence on highly perceptually salient technological information sources (such as computer displays). They can also be designed to mitigate these potential problems by providing an easy to access overview of critical information that might otherwise be neglected or lost from working memory under stress.

Summary of Environmental and Task Factors Impacting SA

Many environmental factors that will exist in the battlespace of the future will have a large impact on the ability of the crew member to achieve the high level of situation awareness that is desired. These include high levels of workload and information overload, physical and psychological stressors, the complexity of both the technological systems they must operate and the components of the battle (such as will be the case with the large network of distributed systems envisioned), the use of automated or semi-automated systems, and the ability of the systems to cut through the fog of war to provide accurate and complete information as needed. These factors necessitate devoting a great deal of attention to designing systems for providing SA.

Situation Awareness, Decision Making, and Performance

Although situation awareness has been discussed as the critical factor for effective decision making and performance in a dynamic environment such as combat, it should be recognized that this linkage is not always direct.

SA and Decision Making

In addition to forming the basis for decision making as a major input, situation awareness may also impact the process of decision making itself. There is considerable evidence that a person's manner of characterizing a situation will determine the decision process chosen to solve a problem. The situation parameters or context of a problem largely determines the ability of individuals to adopt an effective problem solving strategy (Manktelow & Jones, 1987). It is the situation specifics that determine the adoption of an appropriate mental model, leading to the selection of a problem solving strategy. In the absence of an appropriate model, people will often fail in solving a problem correctly even though the same logical process is needed as for a problem they are familiar with.

The way a given problem is presented (or framed) can also determine how the problem is solved (Tversky & Kahneman, 1981; Bettman & Kakkar, 1977; Herstein, 1981; Sundstrom, 1987). Different problem framings can induce different information integration

(situation comprehension), and this determines the selection of a mental model to use for solving the problem. Thus, it is not only the detailed situational information (level 1 SA), but also the way the pieces are put together (level 2 SA) that directs decision strategy selection.

It is important therefore, that decision makers in the combat environment effectively convey their higher level assessments of the situation, as the way in which the data is integrated to form comprehension and projection is critical to decision making. It forms the framing of the problem (what Boyd calls orientation in the OODA loop) that also impacts the search for further information. In addition, one needs to insure that situation specifics are available to the crew member, as it can be the lower level data that allows patterns to be recognized by triggering important memory structures.

SA and Performance

While it is assumed that those with better SA will achieve better performance, this may not always be the case. In general, it is expected that poor performance will occur due to incomplete or inaccurate SA, when the correct action for the identified situation is not known or calculated, or when time or some other factor limits a crew member's ability to carry out the correct action. For instance, in an air-to-air combat mission, Endsley (1990) found that SA was significantly related to performance only for those pilots who had the technical and operational capabilities to take advantage of such knowledge. The same study found that poor SA would not necessarily lead to poor performance if the pilots realized their lack of SA and were able to modify their behavior to reduce the possibility of poor performance. Venturino, Hamilton and Dvorchak (1989) also found that performance was predicted by a combination of SA and decision making (fire-point selection) in combat pilots. Good SA can therefore be viewed as a factor which will increase the probability of good performance, but cannot necessarily guarantee it.

The Role of Uncertainty

"The unifying principle of command and control, the defining problem which overwhelms all others, is the need to deal, one way or another, with uncertainty" (U. S. Marine Corps, 1994). A major factor impacting the link between SA and performance is

the issue of uncertainty (or inversely confidence) regarding one's SA. The amount of confidence crew members have in the accuracy and completeness of the information received and their higher level assessment of that information is a critical element of SA. In the face of uncertainty (low confidence), the crew member can choose to either search for more information (reduce uncertainty and improve SA) or act on uncertain information. As there is rarely absolute certainty, people generally act with an amount of uncertainty that is considered acceptable. How much uncertainty they are willing to accept can be considered a function of the amount of time available for searching for information to reduce the uncertainty and the consequences of acting (or not acting) on the uncertain information. In battle it is recognized that continuing to delay action in order to reduce uncertainty so as to make the best decision is both infeasible (as the situation constantly is changing and thus old data becomes invalid) and undesirable (as delaying too long can sometimes be more costly than acting with partial information) (U. S. Marine Corps, 1994).

Crew members' SA is attributed with a certain degree of confidence based on the source of the information upon which it is founded and their confidence in their ability to process that information into comprehension and projections. The degree to which crew members trust the sensors, individuals, or organizations that supplied the information determines the amount of certainty placed on that information. This information is very important in and of itself, as different degrees of veracity can be ascribed to different sources of information, affecting action selection and providing a means of dealing with dissonant data. This is a significant problem in the combat arena where much information may be either dated, conflicting (such as that generated by two types of sensors), interpreted incorrectly (such as by an inexperienced comrade), or patently false (such as that planted by the enemy). The problem of recognizing the significance of dissonant data and resolving conflicts is a significant one in this environment.

Christ, McKeever, & Huff (1994) discuss how confidence plays a role along with capabilities in determining mission outcomes. As shown in Figure 10, if SA is good and confidence in that SA is high, a person will most likely act to achieve a good outcome (as it will have been possible to make good decisions and plans based on that SA).

		Situation Awareness	
		Good	Poor
Confidence Level	High	**Good Outcome**	**Bad Outcome**
	Low	**Do Nothing (Ineffectual)**	**Okay Outcome (Delay)**

Figure 10. Relationship Between Situation Awareness and Confidence

If with equally good SA the person has a low level of confidence in that SA, however, they most likely will not act on it (choosing to gather more information or behave protectively) and thus be ineffectual. The person with poor SA, if they recognize that it is poor (low confidence level), will correctly choose not to act (or act protectively) and will continue to gather more information to improve SA, thus averting what could be a very bad outcome. The worst situation is that of the person who has poor SA, but has a high level of confidence in that erroneous picture. This person is not just wrong, but dead wrong. Not only will this person be likely to act boldly and incorrectly, but often will draw in others who will be fooled by the false confidence. Of the four possible situations, this is the most dangerous. A critical issue, therefore, is ensuring that not only do people in the battlespace have as good a picture of the situation as possible, but also that they are able to attribute the correct amount of confidence or certainty to that picture.

> *Situation awareness involves far more than simply perceiving information in the environment. It includes comprehending the meaning of that information in an integrated form compared to one's goals, and providing projected future states of the environment. These higher levels of SA are particularly critical for effective decision making in a dynamic environment such as combat.*

SITUATION AWARENESS AND INFORMATION DOMINANCE

The essential challenge in the battlespace of the future will not be the lack of data, but the abundance of it. Getting the right piece of information can easily turn into the problem of searching for a needle in a haystack. The noise to signal ratio can potentially become huge. The solution to this is in *a priori* defining what bits of information are needed by whom so that it can be routed to the right person in a timely manner. The difficulty in meeting this goal is that what is important to one person may only be noise to the next, and these assessments can change rapidly. That is, the difference between information and noise is largely in the eyes of the beholder.

An essential challenge in the battlespace of the future will not be the lack of data, but the abundance of it.

The answer to this dilemma lies in understanding situation awareness. Achieving information dominance is about achieving SA (and denying it to the enemy). SA essentially answers the question of which data is needed by which person, and how that data needs to be processed and presented to turn it into the *information* that is truly needed. And this is the key to true information dominance: Get the right information to the right person at the right time, *and in a form that they can rapidly assimilate and use.*

This is the key to true information dominance: Get the right information to the right person at the right time, and in a form that they can rapidly assimilate and use.

For any given job there are usually a number of goals of varying importance. For instance, a pilot will have, among others, the goals of staying alive, navigating to some

point, and destroying enemies. Each of these goals has many subgoals. In a dynamic environment, these goals and subgoals will vary in priority; some the pilot will actively be working to achieve and others will recede in priority. For example, in the face of an attack by an enemy missile a pilot will be concentrating on the subgoal of missile avoidance and will frequently neglect navigation or other subgoals. One might then assume that only information relevant to the active goals is important. The critical problem with this assumption is that frequently a crew member will not be aware of information that is important for inactive goals, even when they should be. Thus, the pilot may run into the ground while avoiding the enemy missile as he/she has neglected information relative to the goal of maintaining adequate terrain clearance.

This example highlights the fact that goals are dynamic (shifting in relative importance) and that crew members may need information but not realize it at the time (if it is pertinent to an inactive goal, for instance, and thus would indicate that a shift in goal priorities is needed). Therefore, determining what information needs to be provided to each person must be a function of all their possible goals (both active and inactive) in order to allow the dual processes of data-driven and goal-driven processing to be effective. Information needs to be presented based on current goals, goals they may have later, and goals they should be concerned about. By examining the goals for each job function, one can design a system that supplies the needed situation awareness.

Methodologies for determining SA requirements have been developed and applied to different classes of aircraft and non-aircraft systems (Endsley, 1989a, 1993a; Endsley & Rodgers, 1994). A given crew member's SA requirements are essentially a function of their goals and the decisions they must make in order to meet those goals. This determines the data they must acquire, how they need to process that data to form an understanding of the situation (as compared to their goal state), and the projections they must make.

The higher level comprehension and projection requirements are the key determinants of how available information needs to be processed and presented to the crew member in order to be readily assimilated with minimal effort. For example, crew members don't need to know that they are located at a given longitude and latitude. They

need to know where they are in relation to given landmarks (e.g., their base, a fix point, or their target) and goal states (where they are supposed to be). This is the level 2 SA that is needed and can be presented directly. Presenting this information directly, rather than taxing limited working memory capacity, can be quite effective at enhancing SA. Future projection (e.g., how long it will take to get to the next point or how far they can go on the fuel they currently have) can also be easily computed by the system and presented directly.

Shortening the OODA Loop can be accomplished by reducing the time it takes for friendly forces to achieve SA (as this is the most time consuming and critical portion of the loop). Ways to achieve this are presented in Table 3.

Table 3: Shortening the OODA Loop

Reduce time to Achieve SA

- Get the information
  - Real-time sensors, transmission
  - Information selection, fusion, and presentation
- Understand the information
  - Integrate information
  - Compare to goals/ required states
- Project future actions (friendly and enemy forces)
  - Projection information
  - Projection tools
  - Mental Models

Essentially, reducing the time to achieve SA is a matter of three factors:

1. Getting the required information – through the network of sensors and real-time transmission of data, and the selection, fusion, and presentation of that information based on each person's SA requirements

2. Understanding the information – by integrating the data and presenting it relative to the crew member's goal states
3. Projecting the information – in particular the future actions of friendly and enemy forces and their capabilities, both through well developed mental models and by aiding limited human processing power with projection tools. Design guidelines for improving SA can be used to develop systems that support these objectives (Endsley, 1995c).

Conversely, information dominance can be achieved by working to lengthen the enemy's OODA loop. The same principles that have been developed for improving SA can be inverted to reveal strategies for reducing enemy SA and thus increasing the time required to complete the OODA Loop, as shown in Table 4.

Table 4: Lengthening the OODA Loop

<u>**Increase Time to Achieve SA**</u>

- Deny the information or provide incorrect information
  - Overload with information
  - Delay information
- Draw incorrect conclusions from the information
  - Slow down information processing
  - Poorly organize incoming information
  - Representation error
- Instill incorrect assumptions about future actions
  - Subterfuge
  - Unpredictability

Information Warfare is warfare that not only destroys the enemy's ability to act but also their ability to understand. "The aim of a perfect information campaign is to influence adversary choices, and hence adversary behavior, without the adversary's awareness that

choices or behaviors are being influenced" (Szafranski, 1995). Increasing the time required for the enemy to achieve SA can essentially be accomplished by several means discussed below:

1. Deny the enemy information or provide them with incorrect information. These activities are a common part of intelligence operations and wartime activities. In addition, one can act to interfere with enemy SA by overloading them with information. Winston Churchill once said "In wartime, truth is so precious that she should always be attended by a bodyguard of lies." Even if the enemy does have correct information, the provision of large amounts of conflicting information can significantly disguise which information is correct and, at the very least, induce uncertainty and time delays on the enemy. Inducing delays in known enemy communications networks can also subtly lengthen the time for them to achieve SA, possibly without alerting them to the duplicity.
2. Induce the enemy to draw incorrect conclusions from the information they have. As the enemy's picture of the situation will lead to their adoption of a plan, one can also work to affect this overall picture. For instance, during the D-day invasion, the Nazis had information about the possibility of an invasion at Normandy, yet they clung to their overall belief that the invasion would come at Calais and arranged their forces accordingly. A major factor in that assessment was their strong belief that General Patton would lead the invasion. This impression the Allied commanders intentionally created by conjuring up a totally fictitious Army Corps, complete with bogus radio traffic, combat units, and support organizations. These factors led the enemy to develop a false assessment of the situation (a representational error). It has been shown that once an incorrect picture of the situation has been developed, it is very hard to shake that picture, even in the face of conflicting information (Endsley, 1995b; Jones, 1996).
3. Act to disorganize incoming information and slow certain information so that it arrives later can also subtly induce different problem framings and thus different situation assessments. It has been shown that the way information is presented and the order in which it is received can dramatically alter a person's assessment of that

situation from the same data (Tversky & Kahneman, 1981). Adelman et al., for instance, found as much as a five-fold difference in engagement decisions among Patriot air defense officers as a function of the order in which information was presented to them (Adelman, Bresnick, Black, Marvin, & Sak, 1996). The advantage of subtly manipulating the enemy's information presentation is that as the enemy continues to get valid information from its sources, it may not be alert to this type of deception.

4. Instill incorrect assumptions about future actions. Lastly, one can act to alter enemy projections of future behaviors. The feint is a classic example of actions taken to achieve this end. Elaborate subterfuge often exists in warfare to lead the enemy to the wrong projection of friendly actions. In addition, acting in such a way as to be unpredictable is highly important in denying the enemy the ability to project friendly actions. As we move into the information age, it is equally important that any "smart" sensor/weapons systems are equally unpredictable to the enemy; otherwise, a smarter enemy will discover easy means for fooling them.

Summary

By examining the SA requirements of the participants (both friendly and enemy) and the factors that affect SA, the keys to achieving the goal of information dominance are revealed. "No matter what the age or technology, the ultimate measure of command and control effectiveness will always be the same: Can we operate faster and more effectively than the enemy?" (U. S. Marine Corps, 1994). Reducing the decision/action cycle and lengthening that of the enemy is most dependent on the time required to achieve an accurate assessment of the situation upon which to act. Trained personnel are quite adept at forming good plans, once they have a good picture. As the factors impacting situation awareness have been delineated, this foundation points the way towards the development of training and system design solutions for achieving dominance in the battles of the future.

> *Information Warfare is warfare that not only destroys the enemy's ability to act, but also destroys their ability to understand.*

SITUATION AWARENESS IN TEAMS

Team Situation Awareness

To this point the discussion has focused on situation awareness at the level of the individual. In military operations, however, most actions occur in teams or crews of individuals. While SA is essentially a commodity possessed by the individual (because it exists only in the cognition of the human mind), there is nonetheless much to be gained from examining SA as it exists within teams and between teams that are involved in achieving a common goal.

A team is not just any collective of individuals. Rather a team can be defined as "a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/objective/ mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership" (Salas, Dickinson, Converse, & Tannenbaum, 1992). Critical features that define a team therefore include: 1) a common goal, 2) interdependence, and 3) specific roles.

> ***Team***
>
> *A distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership.*
>
> (Salas, et al., 1992)

Within the context of the military, a team may consist of the crew of a single aircraft, such as an E–3 AWACS, or the pilots of a four ship flight of F–16s. The individuals in both cases must act in a coordinated fashion to meet a common goal. This

definition has several implications for the concept of team situation awareness (Endsley, 1889a, 1995b).

In a team, each crew member has a subgoal pertinent to his/her specific role that feeds into the overall team goal. Associated with each crew member's subgoal are a set of SA elements about which he/she is concerned. SA for a team can be represented, therefore, as shown in Figure 11. As the members of a team are essentially interdependent in meeting the overall team goal, some overlap between each member's subgoal and their SA requirements will be present. It is this subset of information that constitutes much of team coordination. That coordination may occur as a verbal exchange, as a duplication of displayed information, or by some other means.

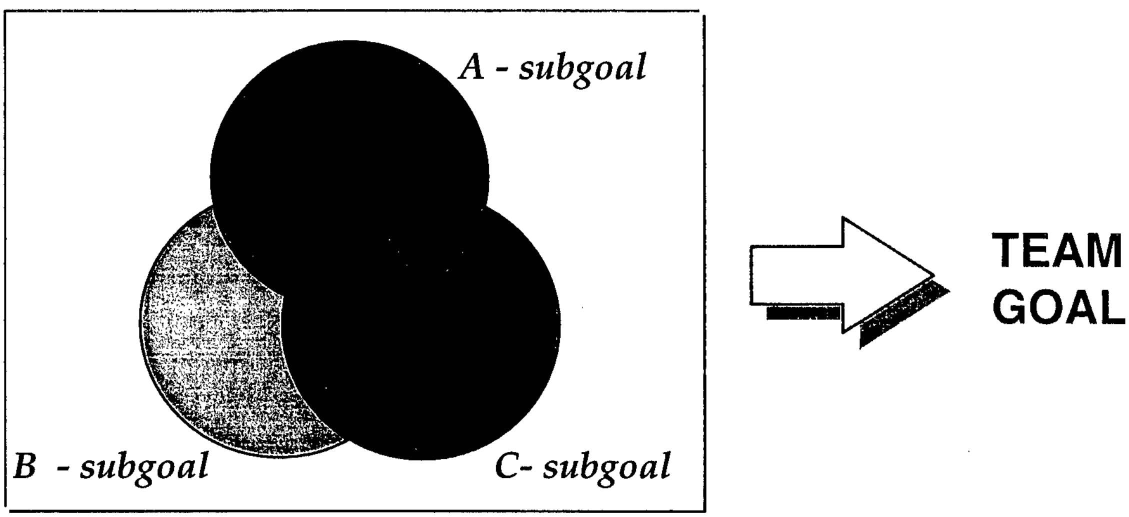

Figure 11. Team Situation Awareness (from Endsley, 1995b)

Overall team SA can be conceived of as "the degree to which every team member possesses the SA required for his or her responsibilities"(Endsley, 1995b). This is independent of any overlaps in SA requirements that may be present. If each of two crew members needs to know a piece of information, it is not sufficient that one knows it perfectly but the other does not. Each and every crew member must have SA for all of his or her own SA requirements or become the proverbial chain's weakest link. For instance, in a multi-pilot aircraft cockpit, both the aircraft commander and co-pilot may need to

know certain pieces of information. If the co-pilot has this information, but not the pilot in command who also needs it, the SA of the team is deficient and performance may suffer unless the discrepancy is corrected.

> ***Team Situation Awareness***
>
> *The degree to which every team member possess the SA required for his or her responsibilities.* (Endsley, 1995b)

Shared Situation Awareness

A major part of teamwork involves the area where these SA requirements overlap the shared SA requirements that exist as a function of the essential interdependency of the team members. Using an F–15E Strike Eagle crew as an example of interdependent team members, one can think of the pilot and the weapons systems operator (WSO) as each having specific functions. Yet it is also clear that they must operate on a common set of data and that the assessments and actions of one can have a large impact on the assessments and actions of the other.

In a poorly functioning team, two crew members may have different assessments on these shared SA requirements and thus behave in a non- coordinated fashion. For example, if the pilot has one picture of where a target is relative to the aircraft, but this is not properly communicated to the WSO, ordinance may not be released at the right time since the WSO's SA will not match that of the pilot. Conversely, if the pilot is not apprised of the aircraft's weapons and target status during the mission and the weapons are released, he/she may be unprepared to take appropriate evasive maneuvers to protect the aircraft and crew from the explosions caused by their own weapons. In both cases, lack of shared SA can create significant problems for the team.

In a smoothly functioning team, each crew member shares a common understanding of what is happening on those SA elements that are common — shared SA. This refers to the overlap between the SA requirements of the crew members as presented in Figure 12.

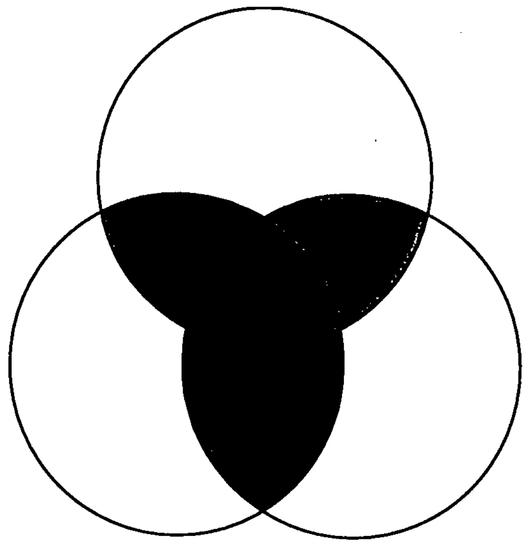

Figure 12. Shared SA Requirements

As depicted by the clear areas of the figure, not all information needs to be shared. Clearly, each crew member is aware of much that is not pertinent to the others on the team. Sharing every detail of each person's job would only create a great deal of noise to sort through to get needed information. It is only that information which is relevant to the SA requirements of each crew member that is needed. Thus, shared situation awareness can be defined as "the degree to which team members possess the same SA on shared SA requirements."

> ***Shared Situation Awareness***
>
> *The degree to which team members possess the same SA on shared SA requirements.*

Different possible states of shared SA exist, as shown in Figure 13. The SA of two crew members may be the same and both be correct. Or, their SA may be the same with both being incorrect. That is, they may share a common but erroneous picture of the situation. Alternately, they may have different pictures of the situation, with one being

correct and one incorrect, or they could be both incorrect in different ways. (As shared SA is only concerned with the SA elements that are common to both crew members, it is essentially impossible for both to be correct but different).

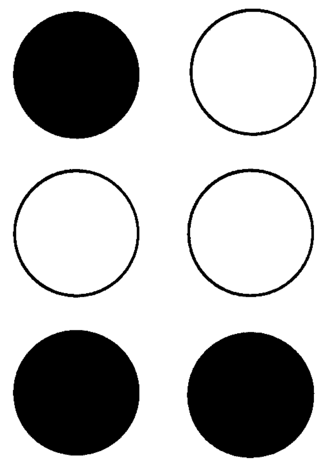

Figure 13. Possible Shared SA States

Obviously the goal is for both crew members to be correct. With good communications and supporting technologies, cases in which there are different pictures of the same situation will be revealed so that the team can take steps to gather information or work to resolve differences. Good crew resource management techniques have been developed for just this reason: to help insure that the best possible understanding of the situation is shared across the team (Robertson & Endsley, 1995). The most dangerous situation is when both crew members share common but incorrect SA. In this case, no immediate dissonance will occur between crew members that indicates there is a problem to be resolved. Often in such a case both crew members may remain locked into their incorrect picture of the situation until some external event occurs to alter it. For instance, in the case of an F–15E crew, receiving a terrain proximity warning of a mountain that shouldn't be on the path they thought themselves to be on.

An examination of how teams develop high levels of SA across its crew members can be undertaken by examining just what constitutes SA requirements in team settings,

devices and mechanisms that are important for achieving high levels of shared SA, and the processes that effective teams use.

Team SA Requirements

Each crew member's SA requirements are essentially a function of their goals and can be specified as such. Shared SA requirements will vary for teams involved in different mission functions and for different operational units; however they can be generally thought of as falling into the categories listed in Table 5.

SA that needs to be shared consists of information at each of the three levels of SA: perception (basic data), comprehension, and projection. Certain basic data about the system being operated and the environment in which the team is operating will generally need to be shared. In addition, information about other crew members may need to be shared. For instance, information regarding actions other crew members have taken and their current capabilities (e.g., as affected by injuries, fatigue, or stress) may be important to another crew member's SA.

Table 5: Shared Team SA Requirements

Shared Information

- Data
  - system
  - environment
  - other team members
- Comprehension
  - status relevant to own goals/ requirements
  - status relevant to other's goals/requirements
  - impact of own actions/changes on others
  - impact of other's actions on self and mission
- Projection
  - actions of team members

Beyond this basic data, which may be transmitted in different ways, shared SA regarding higher level assessments of the situation is also extremely important and needs to be coordinated across crew members. Comprehension needs are largely a function of the interdependencies among crew members' jobs. Crew members need to know the status of all team member activities to the degree that it impacts on each other's goals and requirements. A shared understanding of the impact of the other team members' task status on one's own functions, and thus the overall mission, is important. Similarly, crew members need to know how their own task status and actions impact on other team members so that they can coordinate appropriately.

Finally, in a highly functioning team, crew members are able to project not only what will occur with their system and external events (e.g., enemy actions) but also what fellow team members will do. For example, members of effective teams will instinctively know what other crew members will do in a given situation, where they will be, and with what tasks they will have difficulty. This information is extremely important for operating efficiently as a team as it allows crew members to plan their actions effectively.

Team SA Devices

The processes used for achieving shared SA across a team — how the information transmission occurs — can take place through direct communication, shared displays, or a shared environment, as shown in Table 6. The sharing of SA information may be conducted through a simple verbal exchange (either directly or transmitted by radio or phone), or it may rely on non-verbal communications such as finger pointing or facial expressions.

Much shared information may also be communicated through the use of shared displays of information. That is, different crew members may be able to directly view much of the same information through displays that are available to them (even if these displays are quite different). This would include visual displays (e.g., dials, computer displays, and static written materials) as well as audio displays (e.g., alarms and enunciators) or displays that use other senses (e.g., tactile devices).

A great deal of other information may also be available when the team shares the same environment. In addition to viewing a common world through the canopy of a cockpit, an aircrew receives common information through cues such as the vibration of the aircraft, vestibular perceptions of pitch or roll changes, the pitch of the engines, or the perception of rapid temperature changes, because they share the same environment. This information combines to provide each crew member with important SA about what is happening in their shared situation.

Table 6: Team SA Devices

- Communications
  - Verbal
  - Non-verbal
- Shared Displays
  - Visual
  - Audio
  - Other
- Shared Environment

Team SA Mechanisms

Interestingly, teams are not exclusively reliant on external devices for achieving a high level of SA. They can develop internal mechanisms that greatly facilitate the process of achieving shared SA across the team which are particularly important for the higher levels of SA (comprehension and projection). These higher levels of SA will most likely not be directly available through a crew member's displays and therefore must be communicated between crew members verbally. If, however, the crew members possess a shared mental model (Baker, Salas, Shrestha, & Prince, 1995), each may achieve the same higher level SA without requiring extra verbal communication. This is shown in Figure 14.

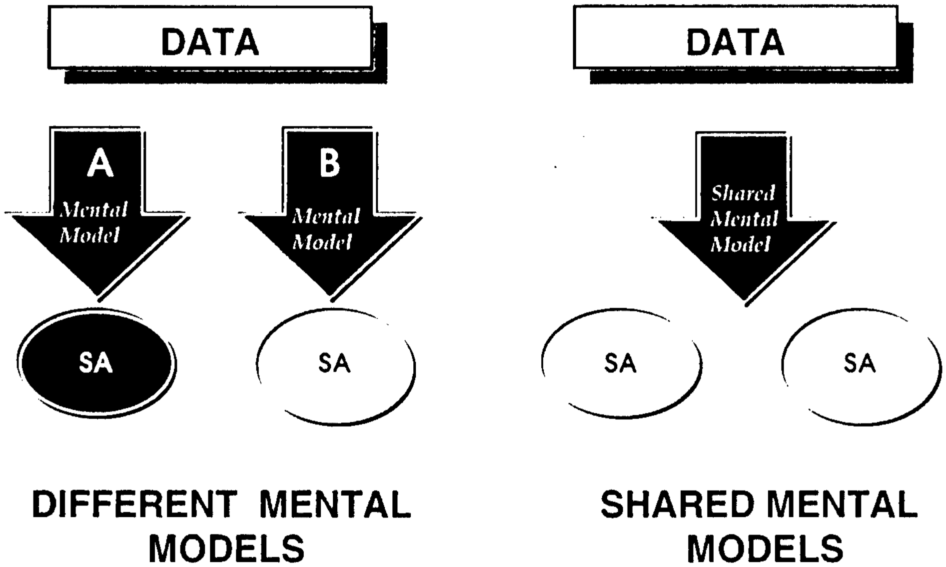

Figure 14. Team SA Mechanisms: Shared Mental Models

The importance of the mental model for interpreting information to form a proper understanding of the situation and projections of future actions has already been discussed. If two crew members have very different mental models then the higher level assessments they make from the same data will be quite different. If they have similar mental models, however, they will arrive at much the same higher level assessments. Thus, the need for a great deal of communication and coordination to convey this information and resolve differences will be negated. They will reach the same shared SA much more directly. Mosier and Chidester (1991), for example, found that better performing aircrews actually communicated less often than poorer performing ones, most likely through the use of these shared mental models. Teams without shared mental models will most likely require a great deal of real-time coordination and communication to ensure that their activities are carried out properly and will be far more susceptible to lapses in this process.

Orasanu and Salas (1993) assert several features regarding the concept of shared mental models:

1. Familiarity among crew members based on shared experience (providing the development of shared mental models) allows aircrews to develop critical interaction

patterns that allow them to perform well, even under extreme fatigue. They are therefore able to adopt a standardized speech pattern (common terms of reference, conventional means of communication, and expectations of other crew members), which allow crew members to interact in predictable ways. (Foushee, Lauber, Baetge, & Acomb, 1996; Kanki, Lozito, & Foushee, 1989).

2. Shared mental models allow crew members to effectively expand their knowledge base by developing an understanding of who has what information, thus developing a "group mind" — a larger shared cognitive resource (Wegner, 1987).
3. Shared mental models are developed through communications, creating a context in which decisions can be made and allowing the resources of the entire group to be exploited (Orasanu, 1990) and ensuring that everyone is solving the same problem.

The concept of shared mental models is not universally heralded, however. For instance, Duffy (1993) raises two questions regarding the advisability of completely shared mental models (or consonant schema):

1. When are shared mental models needed? "If all the team members operate with very similar schema, then why bother having multiple people?"
2. What aspects of mental models need to be consonant — mental models of the problem, overall situation, some sense of the predictability of the situation or a combination?

These are clearly good questions. The mental models of two crew members do not need to be identical, as they have different functions, nor is it likely they will be. If, however, they have enough commonality to allow comprehension and projection regarding actions that affect each other's tasks (as listed in Table 6), then this will be beneficial so long as their shared SA is accurate. Obviously a shared, but incorrect picture does not benefit anyone.

The development of shared mental models has not received much research to date, but it most likely occurs through

1. shared training (e.g., joint training or cross training on different job functions),

2. shared experiences (e.g., experience in working together as a team and similar experiences which may occur either together or individually), and
3. direct communications between team members to build up a shared mental model in advance of operations.

The role and efficacy of each of these mechanisms for developing robust shared mental models needs to be explored.

Team SA Processes

A considerable amount of research has been conducted on factors affecting group decision making and performance. The applicability of much of this work to the combat environment is limited, however, as it has for the most part been conducted with small, artificially constructed groups performing a single, relatively simple task under controlled laboratory conditions (McGrath, 1991). As such, it neglects the important role of the environmental, organizational, and social context on group processes. For instance, early work in the military B–52 found that the pilot's views were more influential than other crew member's views, even when incorrect; conversely, the gunner's and navigator's views were more likely to be neglected, even when correct (Torrance, 1953). These contextual factors are very important for understanding how teams function in complex settings like military operations (Orasanu & Salas, 1993; Young & McNeese, 1995). As with individual decision making, the way in which actual teams in real-world settings function to carry out their diverse activities can be quite different from what is observed under sterile laboratory conditions.

Some studies on team processes have been conducted under more realistic conditions relevant to aviation and combat, however, that are applicable to the issue of team SA. Orasanu and Salas (1993) review a number of applicable studies on team processes in both military and civilian cockpits and describe the following behaviors of effective aircrews:

1. Effective crews engage in contingency planning (particularly during low workload periods), thus developing shared mental models to guide them in emergency conditions (Pepitone, King, & Murphy, 1988; Orasanu, 1990).
2. Effective crews have captains (leaders) who create a democratic environment (thus allowing better sharing of information relevant to team SA) and who explicitly state more plans, strategies, and intentions; consider more options; provide more explanations; and give more warnings or predictions (Chidester, Kanki, Foushee, Dickinson, & Bowles, 1990; Orasanu, 1990). Each of these factors can be seen as explicitly conveying important information for building shared SA.

Effective crews develop a shared understanding of the problem prior to looking for solutions and thereby avoid getting bogged down (Hirokawa, 1983). The importance of developing a shared understanding of the problem has also been expounded by Citera, McNeese, Brown, Selvaraj, Zaff, & Whitaker (1995), who found this factor to be essential for design teams whose members had different backgrounds, each with different jargons and viewpoints. The more diverse the group, the more important developing a shared problem definition may be — another important component of shared SA.

Poorly functioning crews, on the other hand, were characterized as accepting an irrational or incorrect situation model due to

1. the presence of "groupthink," which is characterized by a reluctance to question the consensus of the group or a powerful and respected leader, frequently due to an overriding value for group cohesion over group effectiveness (Janis, 1972);
2. member's reluctance to offer novel information over information commonly shared by the group, again in order to maintain group cohesion (Stasser & Titus, 1987);
3. false assumptions that others share one's opinions (false consensus), that one knows the goals of the others, or that one is the only one with a different opinion (pluralistic ignorance) with pressure to conform acting against the tendency to check these assumptions;
4. rejection of relevant information offered by a lower status crew member by a higher status crew member; and

5. shared misconceptions based on similar, but incorrect shared experiences.

In addition, problems with miscommunication within poorly performing crews and the influence of organizational factors were noted (Orasanu & Salas, 1993).

Duffy (1993) discusses three classes of errors in team decision making:

1. informational errors in which information shared within the crew is misinterpreted as a result of supposedly shared mental models,
2. normative errors in which incorrect or poor models are accepted due to social factors, and
3. structural errors in which global organizational processes and context influence crew performance — mostly at the information acquisition stage.

Klein, Zsambok, and Thordsen (1993) also describe key behaviors that have been found to be important for team performance and decision making in settings such as combat:

1. Roles and functions are explicitly defined for each team member.
2. Team members are actively engaged in the task and their functions.
3. Team members act to compensate to help other team members who are overloaded or having trouble.
4. Team leaders avoid micro-management and attend to their own jobs during a crisis.
5. The team acts to insure that its members all understand the team's goals and plans.
6. The team is able to avoid fixation on a particular focus or perspective, looking at both near term and long term issues and various factors of the situation.
7. The team is able to notice gaps in their picture of the situation and incongruent information.
8. The team encourages the expression of different opinions and then engages in a process of convergence to a common assessment.
9. The team is able to adjust to make necessary changes.
10. The team keeps track of its own progress and manages its time.

Most of these factors can be seen as important to the development of shared mental models and shared SA within the team.

Prince and Salas (1993) have identified seven skills that they believe are important to team SA:

1. Identify problems/potential problems.
2. Recognize the need for action.
3. Attempt to determine the cause of discrepant information before proceeding.
4. Provide information in advance.
5. Note deviations.
6. Demonstrate ongoing awareness of mission status.
7. Demonstrate awareness of task performance and of self.

Taylor, Endsley, and Henderson (1996) recently conducted an exercise that was directly aimed at training situation awareness in a team setting. The exercise involved a task in which teams were required to find a series of objects, carry out a simulated bombing mission, and reach a rendezvous point for rescue by a certain time. Each team member was supplied with instructions and information that were subtly varied so that cooperation and coordination within the team was required. Some of the teams were provided with a video (pre-mission simulation) that walked them through the exercise in advance. Other teams were provided with extra time before beginning the exercise and encouraged to use this time to plan. Unbeknownst to the teams, certain traps were built into the exercise; things did not go exactly as the instructions indicated, and the teams were required to problem solve and improvise to meet their goals. The use of key information imbedded in some individual team member's instructions was useful in avoiding these traps, if it was revealed by the team member and used by the team. In addition, at the end of the exercise a mission change was introduced. The teams were given five minutes to accomplish three goals for extra points that would require the team to delegate tasks and then rejoin. They were informed that they must make the

rendezvous point on time, or they would not be rescued and would therefore fail the main mission. The task was timed, and the teams were in competition with one another.

The performance of the individual teams participating in the exercise was quite varied. Some teams fell into every trap and were ineffective at handling the extra-point scenario at the end. They fell apart at the task of replanning, became completely scattered, and lost sight of the main goal, thus failing the mission. Other teams were much more effective. They were able to pool their information to avoid traps or develop effective team strategies for getting around them. The processes they had in place served them well when the mission change was introduced at the end. They were able to delegate tasks effectively, but did not get distracted with side goals in the pursuit of their major mission goal.

In examining the differences in the processes used by the teams, some interesting observations can be made relative to the concept of team SA. Contrary to expectations, the provision of time for planning prior to the mission made little difference in the teams' performance. This is primarily because all the teams started out with a planning session, even if they had not been given instructions and extra time to do so. The effectiveness of their planning was quite varied, however. The use of the video as a pre-mission simulation to create a set of expectations had a marked effect on performance. Those teams who saw the video performed very well when the mission went as expected (per the instructions and video); however, they were far more likely to fall into the traps. This points to the dangers of expectations when they are false. The trust they developed in the pre-mission simulation proved difficult to overcome when it was wrong, and these teams were less likely to have established key team skills that were necessary for overcoming these obstacles.

Several key team processes and behaviors were observed in the teams that impacted on their ability to develop sufficient team SA to perform the task, as listed in Table 7. The ineffective teams tended to fall prey to the phenomenon of the "SA Blackhole": one team member would have a strong belief in an erroneous picture of the situation or a strong lack of confidence so that he/she would lead others astray and absorb the resources of the group. Contributing to this phenomenon, these teams exhibited a

group norm in which pertinent information was not shared. Team members tended to go along with group sentiment rather than contribute contradictory information in their possession. These groups also failed to prioritize their tasks and goals as a team. Different members went in different directions without setting up coordination. They tended to get caught up in distractions, losing sight of the main goal. They also tended to rely on their expectations and therefore were completely unprepared to deal with events that did not go as planned.

Table 7: Team SA Processes

Ineffective Teams

- SA Blackhole
  - one member would lead others off
- Didn't Share Pertinent Information
  - group norm
- Failure to Prioritize
  - members went in own directions
  - lost track of main goal
- Relied on Expectations
  - unprepared to deal with false expectations

Effective Teams

- Self-checking
  - checked against others at each step
- Coordinated
  - to get information from each other
- Prioritized
  - set-up contingencies
  - re-joining
- Questioning as a Group

- set-up contingencies
- re-joining
- Questioning as a Group
  - group norms

In contrast, the effective teams exhibited a self-checking group norm. At each step in the process they specifically checked with each team member to see if everyone shared the same picture of the situation. They were also much more coordinated as a group. They effectively delegated tasks and acted to get information from each other. These teams were also good at prioritizing. They came up with possible events in advance and planned for these contingencies. The teams, therefore, were able to foresee and deal with some of the traps, even if they did not directly realize that they were present. They also were able to prioritize their goals as a group. They therefore insured that the main goal was not sacrificed to distractions and subgoals that arose. The main norm of these groups was one of questioning. In a positive way they questioned their assumptions and expectations as a group and they questioned each other to gain needed information. These groups were therefore able to develop the best picture of the situation and to establish effective plans in advance.

In some ways the team processes that have been discussed are important for team functioning in general. Many of these processes can be seen to directly impact on the shared SA of the group and on team SA as it consists of each team member's ability to acquire the SA they need. More research is needed to investigate just how highly functioning teams are able to achieve and maintain SA in challenging settings such as combat.

Summary

Research on situation awareness is relatively new, spanning a little over a decade. Research on the issue of situation awareness in a team context is even more recent, and as such is still in its infancy. Nonetheless, several factors important for the situation

awareness of teams and their ability to develop a shared picture of the situation, which is crucial for effective team functioning, have been put forth here. These include an understanding of what constitutes SA requirements in team settings, devices and mechanisms that are important for achieving high levels of shared SA, and the processes that effective teams use.

> *In a smoothly functioning team, each crew member shares a common understanding of what is happening on those SA elements that are common — shared SA.*

SITUATION AWARENESS IN MULTIPLE, DISTRIBUTED TEAMS

Distributed Teams

Team SA has been discussed thus far as involving a single team which exists in some setting, carrying out a common goal. More and more, however, largely due to the capabilities afforded by modern communications and computer networking, these teams may be distributed spatially (in different rooms, structures, or cities) or temporally (working on different shifts, in different time zones, or subject to communication delays). In some settings, they may be simply blocked from each other's direct view by the presence of some obstacle. These teams are distributed. The crew of a B–2 bomber forms a team which shares a common environment. The pilots of a four ship flight of F–16s form a distributed team. Their immediate environment differs, but they share a common, joint goal.

The requirements for team SA in distributed teams are largely the same as for co-located teams. Shared SA is still needed on those SA requirements that overlap between team members, as shown in Figure 15. SA in distributed teams is defined as "SA in teams in which members are separated by distance, time, or obstacles."

> ***SA in Distributed Teams***
>
> *SA in teams in which members are separated by distance, time, or obstacles*

While the requirements for SA in distributed teams are largely the same, many new challenges exist. Of the devices that are important for achieving team SA listed in Table 6, several are not available in distributed teams. These team members do not share a common environment, and non-verbal communications may not be available. While it would seem that the presence of verbal communications and shared information displays

might be sufficient, this belief is misleading. In reality people rely a great deal on physical presence to communicate a great deal of information.

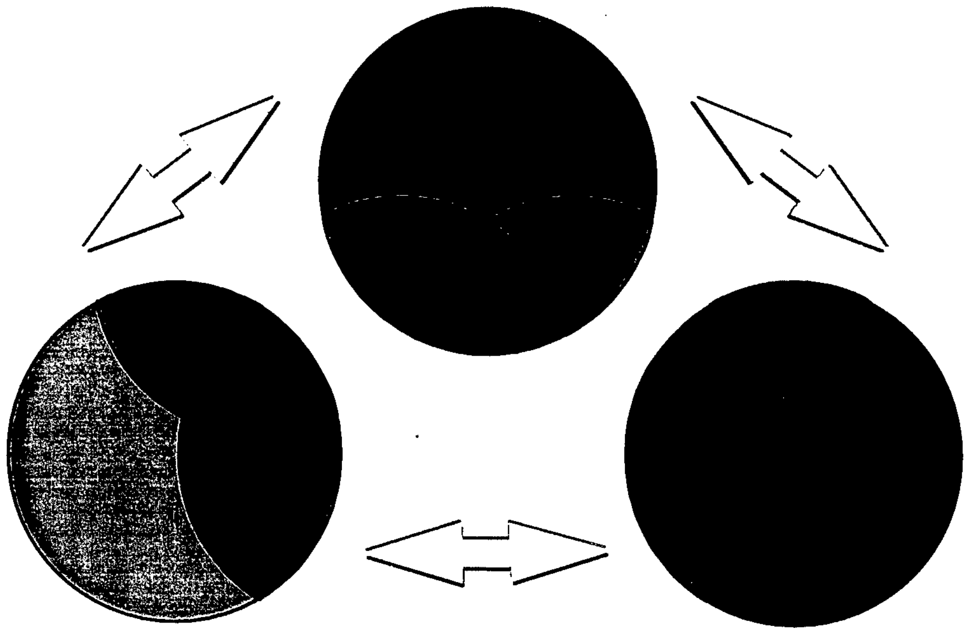

Figure 15. Shared SA in Distributed Teams

For instance, when two people are driving in a car and having a conversation, that conversation will instantly be suspended when a serious traffic problem arises. The passenger is aware of the situation through the fact that the two share a common environment (looking out the window) and by seeing the state of the driver (through muscle tensing or a concerned look). The passenger is therefore able to take this into account and modify behavior accordingly. In contrast, a person without this information would continue talking, distracting the driver, and become consternated when the driver did not reply. Thus, team performance and coordination would be low.

Applied to the military environment, the same problems with crew coordination can arise in situations where crew members are separated, thus disrupting the natural information flow. While the aircrew of a multi-seat cockpit can communicate nonverbally and have the benefit of a shared environment, pilots of separate aircraft must rely extensively on voice communication or shared displays. Conveying needed

information about other pilots over these channels can be more challenging and can induce extra workload. For instance, pilots often rely on the sound of other pilot's voices to convey important information about stress level and competence. This information can be very important to the effective functioning of a multi-ship flight involved in a mission. If radio communications are replaced by electronic data link, much of this information could be lost. Decisions about how to transmit information needs to be guided by a clear understanding of what sources pilots currently use to gain information and what types of information are really important.

The challenge with distributed teams is to make up for the lack of nonverbal and shared environmental information in some other way. The use of video-cameras to provide information through facial gestures might be appropriate in some instances. More emphasis also needs to be given to the development of shared displays to compensate for the lack of these other information sources. The challenge in creating devices for sharing SA in distributed teams is to become aware of both the formal and informal mechanisms used for information flow within collocated teams. This information can be used to insure that other methods of information transfer are made available for distributed teams that do not have the same SA resources available for developing shared SA.

Multiple Teams

In addition to the fact that individuals work in teams, in many settings such as military operations, multiple teams also must work separately but in conjunction to carry out a shared goal, as is depicted in Figure 16. The critical elements of a team are: 1) shared goals, 2) interdependence, and 3) assigned roles. In can be seen that in such a situation, multiple teams also have a greater, shared goal (completing the mission), are somewhat interdependent (as the success of each team is related to the ability of other teams to carry out their goals), and each has an assigned role (a goal or task related to the overall mission goal). The degree of interdependence and goal sharing between separate teams tends to be less than within a team, however.

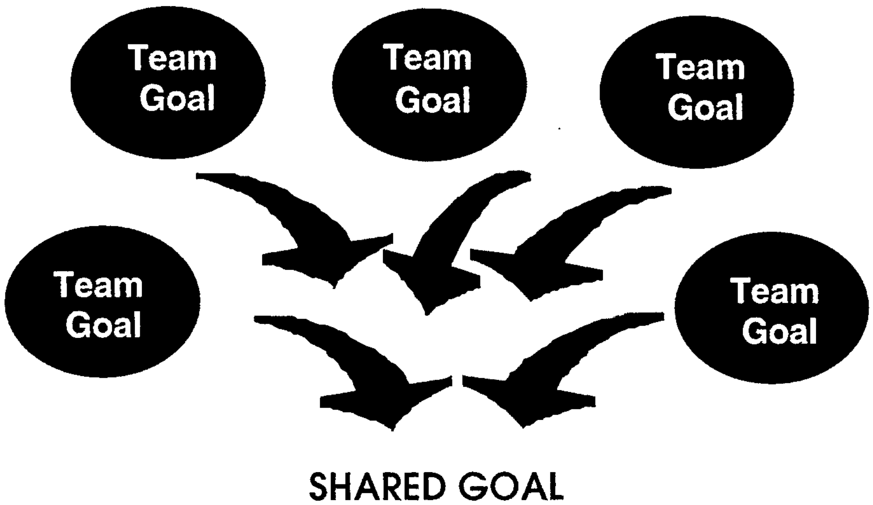

Figure 16. Multiple, Inter-related Teams

In this light, one can think of multiple teams as forming a supra-team. Command and control, surveillance aircraft and systems, transport aircraft, bombers, and fighter aircraft can all form a supra-team who share a common mission goal. As they are somewhat interdependent and share a common overall goal, they also have a need for a certain amount of SA across this supra-team — inter-team SA. The same issues that have been discussed for within team SA are also applicable to the idea of inter-team SA. The requirements for inter-team SA are a function of the degree to which the different teams' SA requirements overlap.

In the past, multiple teams were coordinated through the overall mission plan or air tasking order which assigned very specific roles and time-tables to each team. Command and control served as the major coordinating center for all updates and changes to that plan, as shown in Figure 17. The detailed sharing of SA between teams was minimal.

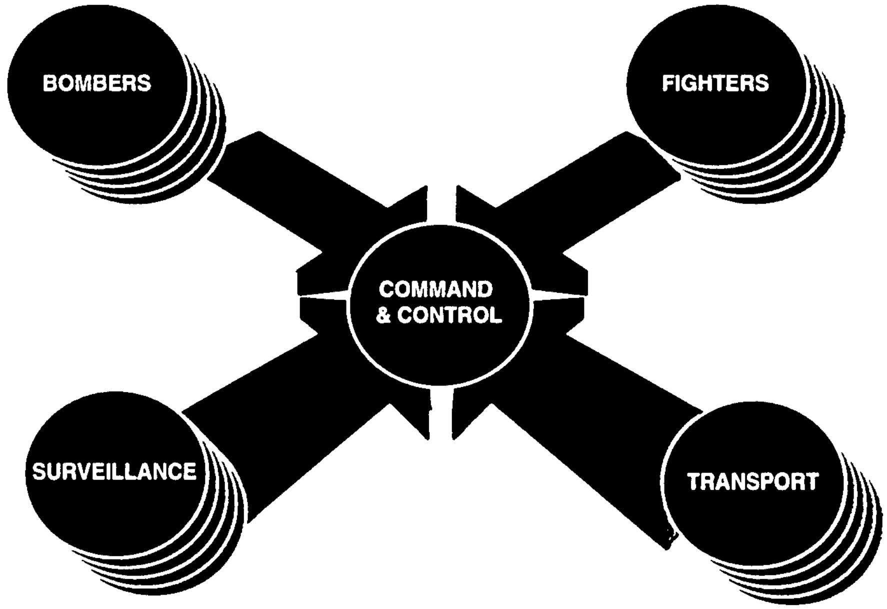

Figure 17. Centralized Communication and Coordination

This structure has several limitations, however, as depicted in Figure 18. The development of plans to cover the multitude of teams involved in an operation is considerably time consuming. Furthermore, by the time the data are gathered and a plan

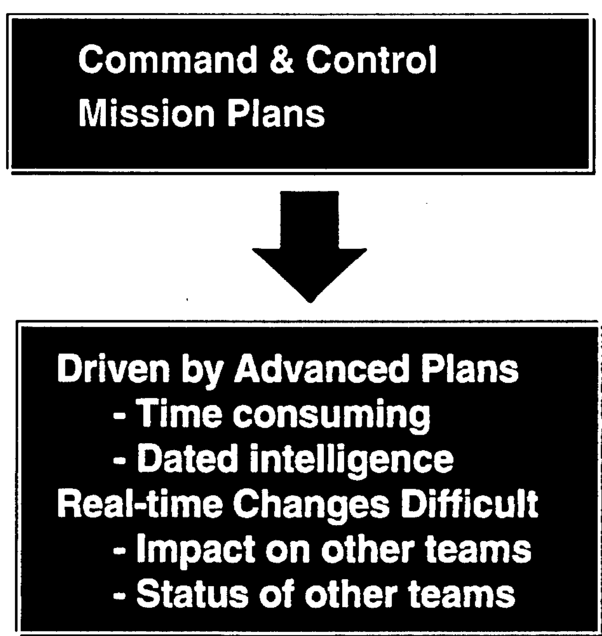

Figure 18. Limitations of Centralized Control

is created and briefed to all of the participants, many factors may have changed, as the intelligence the plan will have become dated. Reducing this cycle to 72 hours during the Gulf War was a major feat. In the future there is a desire to reduce it even further, to make the OODA loop even shorter and more responsive to situational changes. Most difficult is the fact that real-time changes to the plan are difficult. In the course of war, all plans need to be modified to a greater or lesser degree. The situation is frequently different than expected, the enemy does something different than expected, or teams encounter problems or delays in carrying out their part. In this case making real-time changes and informing other teams of the need to make changes has been difficult.

For this reason, future plans are to increase the degree of real-time sharing of information among different military teams, allowing for real-time adjustments to the plan (U.S. Army, 1995; U. S. Navy, 1995; U. S. Air Force Scientific Advisory Board, 1995), as shown in Figure 19. This is the key to reducing the OODA loop and allowing friendly forces to gain the edge on enemy plans and actions.

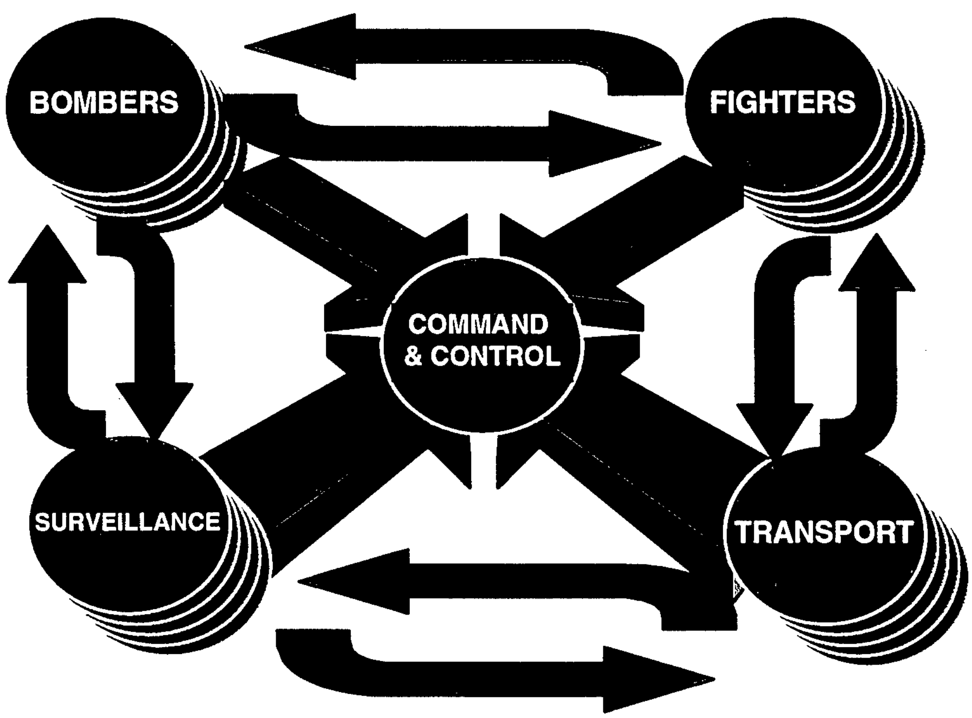

Figure 19. Reducing the OODA Loop: Real-time Sharing of Information

While command and control will still retain a centralized role in overseeing the actions of the many different teams and insuring that forces are used strategically, a greater degree of information sharing between teams will speed up the decision cycle and allow individual operations to be more responsive to situational dynamics.

While this structure will allow greater flexibility and responsiveness, it will also place a much greater reliance on the degree to which shared SA can be developed across the teams in order to be successful. Achieving a high level of shared SA between teams involved in the mission will be critical for insuring each team is able to take advantage of up-to-date information gathered by other teams and adapt effectively to necessary changes in plans. As command and control will no longer be the sole arbiter of information (and thus a potential bottleneck in the information flow), methods and mechanisms for effectively sharing needed information will be the key to achieving true information dominance in the battlespace from the new capabilities the information age has brought.

As command and control will no longer be the sole arbiter of information, methods and mechanisms for effectively sharing needed information will be the key to achieving true information dominance in the battlespace from the new capabilities the information age has brought.

Inter-Team SA

The issues involved in achieving shared SA between teams are actually quite similar to those involved in achieving shared SA between the individuals within a team.

Inter-Team SA Requirements

The degree to which there will be shared SA requirements between teams will be generally less than within a team as usually the goals between teams will be more independent than within teams. There will be a certain degree of overlap, however, which is a function of the interdependence and interaction necessary between teams.

Inter-Team SA Devices

The devices available for achieving shared SA will be essentially the same as those available within the team, bearing in mind that these teams will almost always be distributed (geographically and possibly temporally). Therefore shared SA across teams must rely more on the use of verbal communications or shared displays as these teams will generally not have the advantage of occupying a shared environment.

Inter-Team SA Resources

Significant issues exist regarding the degree to which multiple teams will share a common mental model with which to interpret shared data. Different military units will frequently have very different organizational cultures, jargon and perspectives. These differences will be even greater between military branches or the forces of different countries involved in a coalition effort, and they can sometimes be quite difficult to detect in advance. For instance, the term "engage" has a different meaning for those in the Navy and those in the Air Force that can lead to significant misperceptions of actions and intentions. These issues can create significant barriers to the development of a shared mental model that allows every team to understand the impact of shared information on their own goals and plans or on the goals and plans of others. Either significant training will be needed to help resolve these differences or there will need to be greater incorporation of explicit information in shared displays to compensate for these differences.

Inter-Team SA Processes

As most research has investigated issues affecting processes within teams, there has been relatively little work done on the issue of inter-team processes relevant to SA. Wellens (1993) conducted a series of relevant studies related to SA across multiple teams (fire-rescue teams and police-tow teams) involved in an emergency response scenario. He found that the majority of communications were within team as compared to between team communications. This finding might be appropriate given that one would expect a greater amount of within team task interdependence. Most between team communication dealt with requests for assistance or updates on how the task was going. Rarely was

strategy discussed between teams. Interestingly the provision of "high bandwidth communications" (e.g., audio intercom and broad band two-way television) had no effect on the SA of the teams or their performance when compared to low bandwidth communications conditions (e.g., computer messaging or no communication). Under time stress, people were even more likely to narrow in on their own information displays and neglect remote information (from the other team); a finding which was associated with lower SA and lower performance. Other studies have also shown that communications within teams will decrease under time stress (Entin, Serfaty, & Williams, 1987, Urban, Weaver, Bowers, & Rhodenizer, 1996), most likely an attentional narrowing effect.

When each team was made up of a human and automated component (hybrid teams), however, between team communication increased as the bandwidth of the communication interface increased. Associated with this finding, the amount of SA shared across the team increased (i.e., the remote team was more aware of patterns developing that were affecting the emergency conditions). Interestingly, however, the team in possession of this information became less aware of these patterns — a finding which is most likely due to losses in higher level SA that have also been found for people working with automated systems in several other studies (Carmody & Gluckman, 1993; Endsley & Kiris, 1995).

Wellens concluded that "the kind of information presented across channels was far more important than channel capacity." Abstract representations of information were sometimes better than high bandwidth communications channels that created unwanted distractions and attention obligations.

Endsley and Robertson (1996) have investigated situation awareness between multiple teams involved in aircraft maintenance. They found that there were significant differences in the perceptions and understanding of situations between teams that were related to differences in the mental models held in these different teams. The same information would be interpreted quite differently by different teams leading to significant misunderstandings and system inefficiencies. In addition, they noted problems with not verbalizing the information that went into a given decision (the rationale and

supporting situation information). Only the decision would be communicated between teams. This contributed to sub-optimal decisions in many cases, as good solutions often required the pooling of information across multiple teams. A problem with lack of feedback in the system was also present. The results of a given decision would not be shared back across teams to the team initiating an action. This contributed to the inability of people to develop robust mental models.

Inter-team SA will be needed in the battlespace of the future in order for multiple teams to coordinate effectively. Based on rapidly advancing information, sensing and communications technologies, the ability to share vast amounts of data on an unfolding battle in near real-time is possible. Rapid and effective utilization of this information will allow a dramatic reduction in the degree to which friendly forces are able to reduce their decision cycle.

Issues for Shared SA in Multiple, Distributed Teams

New issues created by the scenario of multiple teams and systems involved in dynamic, distributed decision making in the battlespace are listed below. A discussion of considerations relating to those issues follows Table 8.

Table 8: Issues for Achieving Inter-team SA

- Need Mechanisms for Real-Time Decision Making
  - Non-Real Time is Non-optimal
  - Power Struggles Between Teams
  - Not Informing Other Teams
- Need Better Information Sharing
  - Appropriate Data
  - Who needs What When
- Need Better Sharing of Assessments
  - Goal Impact

- Need Better Support of Real-Time Replanning
  — How Does What They Do Impact Me?
  — Maintain the Big Goal
- Need Methods for Providing SA Information Across Teams

1. First, mechanisms will be needed for making decisions in real-time that affect multiple teams. Methods need to be created for resolving potential power struggles between teams (as each may have slightly different goals).
2. In addition, the tendency not to communicate plan changes or information updates across teams needs to be addressed. The critical factor in providing shared SA across multiple, distributed teams is in determining just what information needs to be shared across teams; both too little information and too much information can create significant problems. To do this, teams need to understand just what information needs to be shared. The question of "who needs what when?" will need to be addressed so that crews do not get too bogged down in inter-team communication and coordination.
3. Crews need to understand that their higher level assessments (comprehension and projections) are important to communicate. The tendency to communicate just data updates (which can be interpreted differently across crews) or just decisions (we are doing this) without supporting rationale needs to be counteracted.
4. In order to support real-time replanning, teams need to be able to assess how a given action or piece of information by another crew impacts on them and the overall mission goal. The tendency to get side-tracked in pursuing the subgoals of the crew at the expense of the mission goal will need to be considered.
5. Appropriate ways for sharing information must be found.

Three major thrusts are envisioned for addressing the issues that exist in creating a high level of shared inter-team SA to support the goal of information dominance:

1) establish SA requirements, 2) support the development of shared mental models, and 3) create a shared battlespace display.

Establish SA Requirements

The information that needs to be shared across teams must be defined. Irrelevant data and too much data can hamper team performance as much as a lack of data. It will either be tuned out by other crews or they will be bogged down in trying to sort through large quantities of data and become distracted from their own duties. A given team essentially needs to know "What is Team B doing? How does it impact us?". This problem can be addressed in a fairly straightforward way by examining the SA requirements of each team and looking at the areas where these requirements overlap. This analysis needs to be conducted across the teams involved in an integrated battlespace as a first step.

Support the Development of Shared Mental Models

Crews probably do not need to have mental models that are extensively similar, as they actually can survive quite effectively in their own microcosms. They do, however, need to incorporate within their mental model a sufficient understanding of other crews to allow them to assess how modifications of other teams' plans and actions impacts on their own plans and on the overall mission goal. A mental model of other teams needs to incorporate an understanding of their roles and plans, the information they need, a means of assessing the impact of situation changes, potential new re-plans, and an ability to project the actions and responses of other teams. These mental models can be created by direct exposure between teams, formal instruction, and most importantly, through joint training exercises.

Shared Battlespace Display

There has been considerable discussion regarding the need for a shared battlespace display to convey battlespace information to everyone (Fogleman, 1995; Owens, 1995). Creating an effective battlespace display will involve many issues. If every detail of the situation is present, finding that which is needed will be highly

problematic. The development of a set of shared SA requirements (at all three levels) should direct the selection of information to be shared and the way that it should be presented to support the SA requirements of each team.

Secondly, just because the displays will be based on common information does not mean that it must be displayed in identical ways to every team. The perspective and information presented to each team needs to be tailored to its individual requirements, even though the displays may be created based on a common database. Each team will have different physical vantage points on the battle, different goal orientations, and different semantics or terminology that must be supported. Yet, each team will also need to be able to communicate with other teams (each with their own orientation, vantage point, and semantics).

The solution to this problem will lie in creating a shared battlespace display that is flexible. It should allow physical shifts (viewing the battle from different angles or vantage points), comparative shifts (viewing the information in relation to different goal states and reference information), and with different information filters (allowing different sets of information to be viewed as relevant to different teams or subgoals). This type of flexibility will do much to aid teams in making cross team assessments of information. It will allow them to be effective at achieving a high level of team SA so as to meet their own goals and in obtaining the shared SA across teams that is necessary to effectively coordinate to meet mission objectives.

Conclusion

Achieving information dominance has arisen as a major goal in future military actions. Developing a large network of sensor systems, computers, and people will not meet this goal, however. Information dominance can only be achieved by creating situation awareness in the individuals and crews that operate in the combat environment (and denying it to enemy forces): This is the key to reducing the decision making cycle and winning the battle. This objective can be achieved through three critical functions:

1. Situation awareness needs to be supported at the level of the individual by insuring that the human interface supplies the information needed for goal attainment in a manner that is compatible with human limitations and processing mechanisms.
2. Team situation awareness needs to be supported, allowing crews to create an accurate and shared picture of each other and their joint status relative to their shared goal.
3. The situation awareness of multiple crews involved in a mission needs to be supported across a distributed space by providing necessary real-time status updates, supporting the development of shared mental models, and developing a shared battlespace display that meets their multiple objectives.

The degree to which the United States will realize its goal of superiority in future military operations will be a function of its ability to capitalize on the capabilities that have been brought by the information age. Achieving information dominance will depend largely on our ability to not only construct large networks of data, but also to manage this data in such a way as to turn it into the information needed for high levels of situation awareness across a wide variety of inter-connected teams. This can be accomplished by understanding the way in which crews form situation awareness in dynamic and complex environments.

The degree to which the United States will realize its goal of superiority in future military operations will be a function of its ability to capitalize on the capabilities that have been brought by the information age.

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